AGRONOMY GUIDE FOR FIELD CROPS

Publication 811

Ministry of Agriculture,
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Ontario

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Introduction

Field crops are produced in Ontario under diverse soil and climatic conditions. The goal is sustainable economic crop production using proven techniques that range from scouting, to soil and fertility management to tillage, planting and harvest practices. These, combined with in-field trials, help producers determine which practices warrant adoption. Good agronomic practices are essential for helping Ontario farmers produce food, fibre and fuel. Successful crop production is dependent upon many inter-related management practices. A little good luck and good weather helps too.

The *Agronomy Guide for Field Crops* is designed to be a technical resource for field crop production. This second edition replaces the 2002 edition. It has been updated with current Ontario research and production recommendations as approved by the:

- Field Crop Research and Services Committee
- Pest Management Research and Services Committee
- Soil Management Research and Services Committee

Sustainable production and responsible use of natural resources are considered in every aspect of the Agronomy Guide.

Some information used in the Agronomy Guide originates from other sources, including the University of Guelph, the Ontario Soil and Crop Improvement Association, the Innovative Farmers Association of Ontario, seed companies, the United States Department of Agriculture (USDA), U.S. universities and other research institutions. Although some data seems dated, where used, this data represents the most relevant and current knowledge available.

The *Agronomy Guide for Field Crops* will be available on the OMAFRA website in its entirety. On many topics discussed in this Guide, OMAFRA has far more information available than can be included here. Additional or updated information can often be found on the crops pages of the OMAFRA website at www.ontario.ca/crops.

Please note that this book does not provide recommendations regarding specific pesticide products for the control of insects, diseases and weeds. For specific information, see OMAFRA Publication 812, *Field Crop Protection Guide*, and Publication 75, *Guide to Weed Control*. Information on ordering these and other OMAFRA publications is found at the beginning of this book. Both of these publications (and any supplements to them) are also available on the OMAFRA website at www.ontario.ca/crops.

1. Corn

Corn is grown with widespread adoption across Southern Ontario. Over the years 1998–2007, grain corn acreage averaged 720,000 ha (1.78 million acres) with an average yield of 7.97 t/ha (127 bu/acre). An additional 121,000 ha (0.3 million acres) is grown as corn silage for livestock feed. Grain corn produced within the province is used for both feed (60%) and industrial (40%) uses.

Tillage

Soil texture and crop rotation are the dominant factors that determine the need for tillage to successfully produce corn in Ontario. Soils in Ontario are usually saturated in early spring, and quick dry-down is necessary to ensure timely corn planting. Appropriate use of tillage can increase spring soil dry-down rates by loosening soil. This improves drainage and/or reduces residue cover, which increases rates of soil water evaporation.

Soil Texture and Drainage

Especially on soils with relatively slow internal drainage, tillage can significantly increase the rate of soil drying and warming, increasing the possibility for timely planting and fast uniform emergence. Generally, in Ontario, there is little corn yield response to tillage on coarse-textured soils (sand, loamy sand or sandy loams) that have good internal drainage characteristics (Drainage classification: rapid or well). This even occurs following crops that leave large amounts of residue cover, such as grain corn or cereals. Table 1–1, *Comparison of Two Tillage Systems on Grain Corn Yield*, this page, provides a summary of Ontario tillage research for corn following either grain corn or cereals grouped according to soil texture. On the coarse-textured sites there was no consistent yield response to tillage. Tillage increased yield about 70% of the time on the medium- and fine-textured sites with an average yield response to tillage of 5%–7%.

Crop Rotation

A good crop rotation can replace a significant amount of tillage. Table 1–1, *Comparison of Two Tillage Systems on Grain Corn Yield*, this page, summarizes Ontario tillage research for corn, conducted on medium- and fine-textured soils, grouped by previous crop. Generally, there is little corn yield response to tillage following forages. Including forages in crop rotations improves soil structure and may eliminate the need for tillage to improve seedbed tilth. The relatively low yield response to tillage following soybeans when compared to either cereals or grain corn is partially due to lower crop-residue levels following soybeans in no-till systems. High residue levels can reduce early-season soil temperature, resulting in delayed planting, slower corn growth and lower yield potential. The possibility that tillage increased corn yield following cereals or grain corn on medium- or fine-textured soils was about 75%, with yield increases averaging 5%–9%.

Table 1–1. Comparison of Two Tillage Systems on Grain Corn Yield

	# Sites	No-Till	Moldboard	Yield Response %	Moldboard Win: Loss
		t/ha (bu/acre)			
Soil Texture Trials conducted following cereals (straw baled) or grain corn (1982–2007).					
Coarse	11	8.22 (131)	8.16 (130)	–0.9	45:55
Medium	79	8.66 (138)	9.16 (146)	5.6	72:28
Fine	42	8.60 (137)	9.16 (146)	6.5	71:29
Previous Crop Trials conducted on medium- or fine-textured soils following various crops (1982–2007).					
Forages	13	8.84 (141)	8.91 (142)	0.7	54:46
Soybeans	50	8.98 (143)	9.04 (144)	0.9	56:44
Cereals (straw-baled)	75	9.23 (147)	9.60 (153)	4.1	71:29
Grain corn	49	7.72 (123)	8.41 (134)	9.1	76:24

Source: Tillage Ontario Database, 2008 (www.tillageontario.com).

Table 1–2. Impact of Fall Tillage Systems on Grain Corn Yield

					Fall Tillage Systems:[1] Corn Yield		
Location	**County**	**Soil**	**Previous Crop**	**No. of Years**	**Moldboard**	**Chisel**	**Offset Disc**
Milton	Halton	clay loam	corn	3	7.34 t/ha (117 bu/acre)	6.84 t/ha (109 bu/acre)	6.84 t/ha (109 bu/acre)
Elora	Wellington	silt loam	corn	7	7.72 t/ha (123 bu/acre)	7.34 t/ha (117 bu/acre)	7.59 t/ha (121 bu/acre)
Elora	Wellington	silt loam	soybeans	2	7.40 t/ha (118 bu/acre)	7.40 t/ha (118 bu/acre)	7.78 t/ha (124 bu/acre)
Comber	Essex	clay loam	soybeans	3	7.78 t/ha (124 bu/acre)	7.34 t/ha (117 bu/acre)	7.78 t/ha (124 bu/acre)
Morpeth	Kent	clay	soybeans	2	6.77 t/ha (108 bu/acre)	6.15 t/ha (98 bu/acre)	6.90 t/ha (110 bu/acre)
Average				**17**	**7.407 t/ha (118 bu/acre)**	**7.017 t/ha (112 bu/acre)**	**7.407 t/ha (118 bu/acre)**

Source: T. Vyn, K. Janovicek, D. Hooker and D. Young, University of Guelph.

[1] All tillage plots received secondary tillage in the spring prior to corn planting. Trials conducted following various crops (1979–96).

Other Reasons for Tillage

There are other reasons to perform tillage for corn production in addition to increasing soil dry-down rates:

- improved seedbed uniformity, resulting in more consistent planter performance and faster, more uniform corn emergence
- incorporation of surface-applied fertilizer or manure, resulting in increased nutrient availability and/or use efficiency
- termination and/or incorporation of weed or crop residue that can serve as hosts to increase populations of insect pests
- alleviation of soil compaction

Conventional Tillage

Conventional tillage for corn in Ontario consists of fall moldboard plowing followed in spring by secondary tillage, usually with a field cultivator or tandem disc. Most moldboard plowing is targeted to an operating depth of 15 cm (6 in.); plowing deeper often results in unwanted mixing of subsoil into the seedbed. The more uniform and level a field is left after fall plowing, the greater the opportunities to reduce secondary tillage costs and improve planter performance. The lack of surface residue in conventional tillage exposes fields to greater erosion risks from water and wind. On complex slopes, tillage can be responsible for causing large quantities of topsoil to move to lower slope positions.

Fall Mulch Tillage

The chisel plow has been the most widely adopted fall mulch tillage tool in Ontario. Tandem and offset discs are also used extensively in some areas. Tillage research trials conducted across Ontario over the past 20 years have generally shown that disking often resulted in more favourable soil conditions and higher corn yields than chisel plowing. Table 1–2, *Impact of Fall Tillage Systems on Grain Corn Yield*, this page, summarizes the corn yield data from these sites.

Chisel plowing with twisted shovel teeth may leave the soil quite ridged. This can lead to extra costs in secondary tillage (more passes), uneven seedbeds and occasionally excessive soil drying. Using sweep teeth on all or part of the chisel plow overcomes some of these problems, as does adding a levelling bar or harrows to the rear of the chisel plow, or timely secondary tillage in the spring.

When disking is done to leave the soil surface level in the fall, single-pass corn planting (no secondary tillage) becomes a viable option in the spring and is a good technique for reducing tillage costs. Table 1–3, *Impact of Fall Tillage Systems Without Secondary Tillage on Grain Corn Yield*, opposite page, outlines research conducted in Ontario where this approach was taken. On those sites where fall chisel plowing and secondary tillage were compared, the tandem disc-only treatment generally produced higher yields and had significantly lower operating costs. On average, using only the tandem disc yielded within 0.31 t/ha (5 bu/acre) of the conventional tillage system.

Table 1–3. Impact of Fall Tillage Systems Without Secondary Tillage on Grain Corn Yield

Location	County	Soil	Previous Crop	No. of years	Tillage Systems:[1] Corn Yield Moldboard	Chisel	Fall Tandem Disc Only
Alvinston	Lambton	clay	soybeans	3	5.96 t/ha (95 bu/acre)	5.39 t/ha (86 bu/acre)	5.71 t/ha (91 bu/acre)
Fingal	Elgin	silty clay loam	soybeans	3	9.97 t/ha (159 bu/acre)	9.66 t/ha (154 bu/acre)	9.66 t/ha (154 bu/acre)
Centralia	Huron	silt loam	wheat straw baled	3	9.16 t/ha (146 bu/acre)	8.72 t/ha (139 bu/acre)	8.84 t/ha (141 bu/acre)
Wyoming	Lambton	silty clay loam	wheat straw baled	3	9.97 t/ha (159 bu/acre)	9.72 t/ha (155 bu/acre)	9.85 t/ha (157 bu/acre)
Average				**12**	**8.78 t/ha (140 bu/acre)**	**8.41 t/ha (134 bu/acre)**	**8.53 t/ha (136 bu/acre)**

Source: T. Vyn, K. Janovicek, D. Hooker and G. Opuku, University of Guelph.

[1] Moldboard and chisel plots received spring secondary tillage; fall tandem disc-only plots were planted directly in the spring without any secondary tillage.

Spring Mulch Tillage

The best practice for reducing erosion and input costs is to not perform fall tillage. Producers working on fine-textured soils where crop residues are high following corn, wheat or other crops may be apprehensive about leaving soils untouched in the fall. However, following soybeans, there is little justification for doing fall tillage on most fields in Ontario. Table 1–4, *Tillage System Effects on Grain Corn Yield Following Soybeans*, this page, illustrates that even on finely textured soils, spring tillage alone (two passes of a field cultivator) was generally sufficient when corn followed soybeans in the rotation. Other demonstration trials established on medium- and coarse-textured soils have shown the same.

> When corn follows soybeans, systems that involve more than spring cultivation often do not produce enough extra corn to pay for the fall tillage operation.

Grower experience with spring mulch tillage systems has shown that working undisturbed soils in the spring obtained better results when using high-clearance tines, narrow teeth and/or when packers or rollers were used in conjunction with the field cultivator.

Fall Strip-Tillage

Performing fall tillage confined to narrow zones that correspond to next year's corn rows has received considerable attention in the past few years. The strips of soil are loosened, cleared of residue and hopefully somewhat elevated, while leaving the rest of the field covered with protective crop residue. The next spring, the strips are drier, less dense and more suited to "no-till" planting.

Research conducted at the University of Guelph over the period 1994–96 compared a Trans-till zone tillage tool to conventional and no-till systems in winter wheat stubble. Table 1–5, *Fall Strip-Tillage for Corn After Winter Wheat (straw baled)*, next page, indicates that on fine-textured soils, strip-tillage in the fall generally produced yields that were better than no-till. Only at Wyoming did fall strip till yields equal those obtained

Table 1–4. Tillage System Effects on Grain Corn Yield Following Soybeans

	Silty Clay Loam	Clay
Tillage System[1]	**Grain Corn Yields @ 15.5%**	
Fall moldboard + spring tillage	9.97 t/ha (159 bu/acre)	6.02 t/ha (96 bu/acre)
Spring tillage only	9.78 t/ha (156 bu/acre)	6.02 t/ha (96 bu/acre)
No tillage	9.65 t/ha (154 bu/acre)	5.65 t/ha (90 bu/acre)

Source: T. Vyn, D. Hooker and C. Swanton, University of Guelph.

[1] Trials were conducted on fine-textured soils at Fingal (silty clay loam) and Alvinston (clay) (1994–96).

Table 1–5. Fall Strip-Tillage for Corn After Winter Wheat (straw baled)

Tillage System[1,2]	Soil Moisture in Early May	Yield	
		Fine-Textured Soil	Medium-Textured Soil
Fall moldboard	23.3%	9.97 t/ha (159 bu/acre)	9.22 t/ha (147 bu/acre)
Fall zone-till	25.6%	9.97 t/ha (159 bu/acre)	8.72 t/ha (139 bu/acre)
No-till	29.8%	9.35 t/ha (149 bu/acre)	8.47 t/ha (135 bu/acre)

Source: T.J. Vyn, 1997, University of Guelph.

[1] Trials were conducted on fine- (Wyoming) and medium- (Centralia) textured soils (1994–96).

[2] Moldboard and chisel-plowed plots were cultivated and packed in spring. Fall disc and zone-till plots were planted directly without any secondary tillage in spring. All treatments were planted the same day.

with the conventional moldboard system. Subsequent Ontario research has supported the observations shown in Table 1–5; that on fine-textured soils following wheat, fall strip-tillage generally gave higher corn yields than no-till and equal yields to those of conventional tillage systems. Research results have not consistently shown a yield advantage for fall strip-tillage systems over no-till on medium-textured soils or when following soybeans.

Early spring moisture measurements conducted on University tillage plots generally showed that fall strip-tilled zones were consistently drier in early May compared to the undisturbed no-till plots (Table 1–5).

Yield responses in side-by-side trials have not always indicated a benefit to fall strip-tillage, but producers with large acreage, poorly draining soils or high surface residues may gain a consistent benefit from strip-tillage in terms of planting timeliness, emergence uniformity and early corn growth. Performing secondary spring strip-tillage in fall strip-tillage zones has increased yields in instances where fall strip-tillage yields are less than those in conventional tillage systems. If conducting spring strip-tillage, do not exceed a tillage depth of 10 cm (4 in.), in order to minimize the risk of excessive soil drying that can occur, especially in dry planting seasons.

Table 1–6. Corn Yield Response to Application Method of Phosphorus and Potassium Fertilizer in Two Tillage Systems

	Soil Test K Rating	
	Fall P & K Only[2]	Planter P & K Only[3]
Tillage System[1]	t/ha (bu/acre)	
Medium Responsive		
Fall strip-tillage	8.10 (129)	8.10 (129)
No-till	7.53 (120)	8.10 (129)
High Responsive		
Fall strip-tillage	5.71 (91)	7.28 (116)
No-till	4.52 (72)	7.09 (113)

Source: Stewart, Janovicek and Deen. University of Guelph, 2005.

[1] Average of 5 trials conducted on medium-textured soils with medium soil test K ratings (1 trial with a low soil test K rating).

[2] Fall phosphorus (40 lb P_2O_5/acre on medium testing sites and 125 lb P_2O_5/acre on the low testing site) and potassium (100–125 lb K_2O/acre) were fall-surface broadcast in the no-till system and banded 6 in. deep in the fall strip-till system.

[3] Planter phosphorus (30 lb P_2O_5/acre) and potassium (30 lb K_2O/acre) were applied in a band 5 cm (2 in.) beside the row, 5 cm (2 in.) below seeding depth.

Strip-tillage systems also provide an opportunity to band fertilizers that in a no-till system must be broadcast. Applying fertilizer using the strip-tillage system may also replace the need to apply banded starter fertilizers through the planter. Table 1–6, *Corn Yield Response to Application Method of Phosphorus and Potassium Fertilizer in Two Tillage Systems*, this page, shows that fall banding of phosphorus and potassium in strip-tillage systems can produce higher yields than when similar rates of fertilizer were broadcast in no-till systems. However, corn yields from using strip-tillage systems to band-apply phosphorus and/or potassium in the fall have generally been lower than when P and K have been applied through the planter.

Deep Tillage

Increasing axle loads of farm machinery and the general concern that soils have become more compacted have increased the use of deep tillage systems. The main reason offered for deep tillage is that elimination of compacted sub-soil layers and/or tillage pans will promote rapid and deep root growth and improve drainage. However, in Ontario, subsoils loosened using deep tillage are often easily re-compacted by wheel traffic. Moreover, it is possible that deep-tilled soils that receive wheel traffic end up with poorer drainage and are less favourable for root growth because deep tillage destroyed the natural pores created by worms or previous crop roots.

Table 1–7. Grain Corn Yield Response to Three Tillage Systems

Tillage[1]	Soybeans	Wheat
	t/ha (bu/acre)	
Fall disk ripper (12–14 in.)	9.73 (155)	9.73 (155)
Fall strip-tillage (6–8 in.)	9.48 (151)	9.73 (155)
No-till	9.54 (152)	9.29 (148)

Source: Ontario Tillage Database, 2008 (www.tillageontario.com)

[1] Trials were conducted on medium- (loam or silt loam) textured soils following soybeans (4 sites) and winter wheat (8 sites) (2002–05).

In Ontario, use of the disk ripper to conduct deep (30–35 cm or 12–13 in.) tillage has increased significantly. Table 1–7, *Grain Corn Yield Response to Three Tillage Systems*, this page, summarizes the results of a study that evaluated corn yield response to deep tillage using a disk ripper in medium-textured soils. On these productive soils, with little evidence of severe subsoil compaction, there was little yield advantage and no economic advantage over a fall strip-tillage system where soils were tilled at about half the depth. Following wheat, both the disk ripper and fall strip-tillage systems produced yields that were 5% over no-till, but all of the yield response from tillage could be obtained using a fall strip-tillage system with a tillage depth about half that of the disk ripper. Some growers have claimed benefits from deep tillage on areas with poor drainage or severe soil compaction (such as headlands). The need for deep tillage in Ontario is often only associated with fields or areas of fields with severe drainage limitations or soil compaction.

The strip-tillage system has also been presented as an opportunity for reducing compaction and/or improving drainage by conducting deep tillage. In some cases, recommendations are made to till as deep as 30–35 cm (12–14 in). University of Guelph researchers tested deep in-row ripping in 1998–2000 at sites near Granton and Ridgetown. Table 1–8, *Effects of Tillage Systems on Corn Yields Following Winter Wheat*, this page, illustrates that deep loosening either provided no yield benefit or not enough to pay for the cost of the deep tillage operation. The advantage of using a strip-tillage system to perform deep tillage is that wheel traffic does not occur on the deep tilled strips until the next harvest, which allows extra time for soil stabilization before being exposed to wheel traffic again.

Table 1–8. Effects of Tillage Systems on Corn Yields Following Winter Wheat

Tillage System	Granton (loam–clay loam soil)	Ridgetown (clay loam soil)
	t/ha (bu/acre)	
Fall moldboard	11.35 (181)	7.78 (124)
Deep fall zone-till (30 cm (14 in.))	10.79 (172)	8.15 (130)
No-till (3-coulters)	10.73 (171)	7.65 (122)
No-till (row cleaners)	10.85 (173)	7.78 (124)

Source: T. Vyn, B. Deen K. Janovicek, D. Young, University of Guelph (1998–2000).

No-Till Systems

In no-till systems, tillage is not used to prepare a seedbed. Minimal soil loosening in a narrow band immediately ahead of the seed opener is performed by planter-mounted coulters and/or residue clearing devices. Successful no-till corn production is partially dependant on effective use of alternative production practices and field management strategies that deal with yield limiting factors that otherwise would have been corrected with tillage.

For successful no-till corn production, pay attention to:

- soil drainage
- crop rotation
- residue management
- weed control
- disease/insect management
- fertilizer placement
- soil compaction
- planter performance

Soil Drainage

Without the soil loosening and residue incorporation associated with tillage, soils experience slower spring drying rates in no-till systems. This can delay planting and possibly decrease the number of days available for timely planting. Effective tile drainage is necessary for many Ontario soils to ensure a reasonable opportunity for timely no-till corn planting and a favourable seedbed environment for rapid, deep root growth. Producers often discover that no-till is very difficult to do successfully in fine-textured soils that are not systematically tile drained. These fine-textured fields with inadequate tile drainage will require some type of fall tillage to maximize yield potential.

Table 1–9. Effect of Wheat Straw Levels on No-Till Corn Yields

Tillage System/Straw Level[1,2]	Yield
No-till / all straw and stubble remain	9.16 t/ha (146 bu/acre)
No-till / straw baled but stubble remains	9.35 t/ha (149 bu/acre)
No-till/ straw baled and stubble cut and removed	9.91 t/ha (158 bu/acre)
Moldboard/ straw baled but stubble remains	9.97 t/ha (159 bu/acre)

Source: T. Vyn, G. Opuku and C. Swanton, University of Guelph.

[1] Average 1994–96. Wyoming, Ontario.

[2] Stubble heights were approximately 25–30 cm (10–12 in.) except for plots where stubble was cut and removed.

Crop Rotation

In Ontario, no-till corn generally produces similar yields to tilled systems when following crops that produce low residues, such as soybeans, dry edible beans or forages that were harvested as hay or haylage. For soils with relatively slow internal drainage, increasing the amount of surface residue cover can slow soil drying, resulting in a reduced opportunity for timely planting and seedbed conditions that promote fast, deep, early-season root growth. Improved soil structure and higher earth worm activity associated with soils following forages may contribute to the success of no-till corn production following forages.

No-till corn grown on medium- and fine-textured soils, following crops that produce high residue, often struggle to achieve successful crop yields regardless of what else is done correctly. Following high-residue crops, such as grain corn or cereals, if it is not possible to remove residue (i.e., straw or stover baling), some tillage will probably be required to increase the chance of timely planting and maximum yield potential.

Residue Management

Reducing tillage costs for corn, improving net profits and enhancing the long-term health of the soil requires decisions about how best to handle crop residues, particularly wheat straw. Where no-till or reduced till corn is to follow wheat, remove the wheat straw from the field. Table 1–9, *Effect of Wheat Straw Levels on No-Till Corn Yields*, this page, summarizes the corn yields from tillage trials where three different levels of straw were left on the field and corn was no-till planted the following year. Removing straw from fields, especially in high-yielding wheat crops and on heavier-textured soils, increased the potential for no-till corn yields to equal those of moldboard plowing.

Where straw removal is not an option, uniform spreading of the straw and chaff is critical for no-till or reduced tillage success in corn. Even where straw is to be left in the windrow, it is important to spread the chaff as widely and evenly as possible during combining. In cool, wet springs, the lower soil temperatures, poorer growth and potential slug damage brought on by mats of decaying wheat residue often result in yield losses that may have been avoided by uniform residue spreading.

Where the risks of water and wind erosion are low, the benefits of incorporating all the straw might outweigh the advantages of reducing tillage. For farms where erosion potential is higher, adopting a reduced tillage system, even with the need to remove some straw, is probably more sustainable. Another option is using a system where wheat fields receive a small amount of tillage to partially incorporate straw while still leaving the soil surface largely protected.

The impact of adding nitrogen to assist in straw breakdown was tested by researchers at the University of Guelph. Results indicate that where nitrogen was spread on wheat straw in the fall, it did not cause straw to decay more quickly. In addition, the soil nitrogen levels the following spring were not higher compared to where no nitrogen was applied.

Weed Control

For corn yield potential to be realized, optimum weed control is required. Extra management in no-till cropping systems may be needed to control perennial weeds and weed species that are new to the system (due to a shift in weed populations). Spring pre-plant burndown treatments are critical in allowing the crop to develop without interference during critical early growth phases.

Disease and Insect Management

Certain insect pests (i.e., armyworm, black cutworm) can be more of a problem in no-till systems, because lack of tillage can increase the probability that host plants are present, allowing populations of these pests to establish and multiply. Risk of damage from insect pests that over-winter or establish because host plants are present in no-till fields can be minimized by using fall burn-down herbicides. These effectively kill any weeds or perennial crops that would have otherwise over-wintered and started to regrow the following spring. More details on control measures for insects, pests and diseases for corn can be found in Chapter 13 and Chapter 14.

Fertilizer Placement

Studies in Ontario indicate that nutrient stratification (nutrients concentrated near the soil surface) may occur in

Table 1–10. Corn Yield Response to Phosphorus and Potassium Fertilizer Placement in Two Tillage Systems

Trials were conducted on medium-textured soils.

	Soil K Rating[1]			
	No Fall P & K		Fall P[2] & K	
	No Planter P & K	Planter P & K	No Planter P & K[3]	Planter P[4] & K
Tillage	t/ha (bu/acre)			
High				
Fall moldboard	9.23 (147)	9.10 (145)	8.72 (139)	9.10 (145)
No-till	8.72 (139)	8.91 (142)	8.98 (143)	9.23 (147)
Medium				
Fall moldboard	9.04 (144)	9.23 (147)	8.79 (140)	9.10 (145)
No-till	8.54 (136)	9.23 (147)	8.60 (137)	9.04 (144)
Low				
Fall moldboard	5.02 (80)	8.29 (132)	7.97 (127)	9.35 (149)
No-till	2.07 (33)	7.09 (113)	6.21 (99)	8.91 (142)

Source: G. Stewart, OMAFRA, and K. Janovicek (University of Guelph).

[1] Average of 3 trials with high soil test K rating; 2 trials with a medium soil test K rating and 1 trial with a low soil test K rating.

[2] Fall phosphorous (40 lb P_2O_5/acre on low and moderately responsive testing sites and 125 lb P_2O_5/acre on the highly responsive testing site).

[3] Potassium (100–125 lb K_2O/acre) was surface fall broadcast and incorporated in the fall moldboard system and fall broadcast and not incorporated in the fall strip-till system.

[4] Planter phosphorous (30 lb P_2O_5/acre) and potassium (30 lb K_2O/acre) was applied in a band 5 cm (2 in.) beside the row, 5 cm (2 in.) below seeding depth.

long-term, no-till fields. Without the option to incorporate or mix dry fertilizer material in the no-till system, fertilizer placement becomes increasingly important.

Table 1–10, *Corn Yield Response to Phosphorus and Potassium Fertilizer Placement in Two Tillage Systems*, this page, summarizes the results from a series of studies that evaluated phosphorus and potassium fertilizer placement in conventional and no-till systems. Generally, applying phosphorus and potassium in starter fertilizer bands decreased yield differences between fall moldboard and no-till systems, especially when soil test K levels were medium or low. Planter-banded phosphorus and potassium were utilized more efficiently compared to fall surface broadcast in no-till systems. However, on high response sites, a combination of broadcast and planter banding may be necessary to maximize no-till yields.

Table 1–11. Effect of Planter Model and Tillage on Corn Yield

	Moldboard	No-Till
Planter[1]	t/ha (bu/acre)	
John Deere 7000 (1986 model)	8.10 (129)	7.09 (113)
John Deere 1750 (1998 model)	7.91 (126)	7.59 (121)

W. Liu and B. Deen, University of Guelph.

[1] Average of trials conducted on medium-textured soils at Elora and Woodstock (2000–01).

These results are consistent with other Ontario and U.S. Corn Belt research under similar conditions that has shown that planter-banded potassium reduced corn yield differences. Cooler and less aerated soils in no-till systems often have a slower rate of nitrogen mineralization compared to conventional tillage systems. This is often overcome by applying 35 kg/ha (31 lb/acre) of nitrogen in the starter fertilizer.

> Applying 35 kg/ha (31 lb/acre) of nitrogen in the starter on no-till corn planters has been shown to overcome the slower nitrogen mineralization often present in no-till soils, when the balance of the nitrogen is applied in a side-dress application.

Soil Compaction

Soil compaction is often cited as one of the reasons no-till may yield less than conventional tillage corn. An option for enhancing corn yields in reduced tillage systems may include extensive loosening deeper into the soil profile. This can be done without disrupting much of the crop residue on the soil surface and can be confined to zones where next year's corn rows will be planted (i.e., strip-tillage).

Usually the most effective method to minimize compaction risk is to reduce the number of field operations and/or minimize use of equipment with heavy axles (e.g., grain buggies) wherever possible. Avoiding field traffic when soils are excessively wet will also help minimize compaction.

Planter Performance

Optimal planter performance is necessary to maximize corn yield potential in any tillage system. However, planter performance and/or suitability are especially critical in no-till systems due to the lack of tillage that results in greater variability in near-surface soil properties and residue cover. Table 1–11, *Effect of Planter Model and Tillage on Corn Yield*, this page,

Table 1–12. Old and New CHU Comparisons for Various Locations in Ontario

Accumulated crop heat units over the course of an average growing season at various locations across Ontario

Sites	1961–1990 CHU (starts after 3 days of 12.8°C)	1971–2000 CHU-M1 (starts May 1st)
Ridgetown	3342	3462
London	2899	3120
Walkerton/Hanover	2680	2759
Guelph	2682	2828
Belleville	3139	3369
Ottawa	2885	3099
Thunder Bay	1789	2058
Earlton	1934	2228

suggests that yield differences between moldboard and no-tillage systems can be reduced by using newer model corn planters. There was less variability in emergence associated with the newer model planter in the no-till system, which probably explains why no-till yields were higher for this model. See Table 1–22, *Effect of Planter Type on Corn Spacing Variability*, on page 17, for more detailed information on the effect of plant spacing and emergence variability on corn yield. Ensuring that planting equipment is properly maintained or upgraded to models better suited for no-till planting conditions will lessen corn plant stand and emergence variability, and increase no-till yields.

Hybrid Selection

Maturity Ratings

Corn development is driven primarily by temperature, especially during the planting-to-silking period. Unlike soybeans, day length has little effect on the rate at which corn develops. The Ontario Crop Heat Unit System has been developed to calculate the impact of temperature on corn development. Ontario crop heat units (CHUs) are calculated based on daily maximum and minimum temperatures and allow for a numerical rating of growing seasons, geographical locations and corn hybrids. This system allows growers to select hybrids that have a high probability of reaching maturity before a killing frost.

Revised Ontario Crop Heat Units

CHU calculations require a start date, a formula for calculating CHU based on daily temperatures and an end date. Traditionally, the start date was triggered by the first occurrence of three consecutive days that reached an average temperature of 12.8°C. Starting in 2009, Ontario is modifying the CHU start date to be May 1, regardless of location or temperatures experienced up to that date. To avoid confusion, these new CHU designations will be referred to as CHU-M1. The new CHU-M1 system will use the same calculation to arrive at a daily CHU total and will use the same season-ending date (30-year daily average temperature falls below 12°C, or first occurrence of −2°C)). The other change included in the CHU-M1 system is that the 30-year normal temperatures used to identify averages have been updated from the 1961–1990 to the 1971–2000 period. The numerical changes between the new CHU-M1 and former CHU system are summarized in Table 1–12, *Old and New CHU Comparisons for Various Locations in Ontario*, this page, and Figure 1–1, *Crop Heat Units (CHU-M1) Available for Corn Production*, opposite page.

Table 1–13. Approximate Conversions Between Three Systems of Measuring Heat Accumulation in a Growing Season

Location	Ontario Crop Heat Units (CHU-M1)	Corn Relative Maturity (CRM)	Growing Degree Days (Base 10) (GDD or GDU)
Walkerton	2,759	84	2,000
Guelph	2,828	84	2,012
Ottawa	3,099	91	2,174
London	3,120	92	2,203
Simcoe	3,190	94	2,268
Belleville	3,369	98	2,353
Ridgetown	3,462	104	2,511
Harrow	3,702	111	2,673

It takes approximately 75–80 crop heat units to produce each corn leaf. Therefore, at temperatures of 30°C during the day and 20°C at night, there is one new leaf every 2–3 days. At 20°C during the day, and 10°C at night, one new leaf appears every 5–6 days.

Other jurisdictions use different systems for quantifying the effect of temperature on corn development and for rating corn hybrid maturity. Unfortunately, these systems are unique, and true mathematical conversions from one to the other are not possible. Table 1–13, *Approximate Conversions Between Three Systems of Measuring Heat Accumulation in a Growing Season*, this page, provides values to assist in making reasonable comparisons between the different systems.

Producers who record daily high and low temperatures can use Table 10–4, *Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures*, on page 181, to calculate CHUs for their own farm.

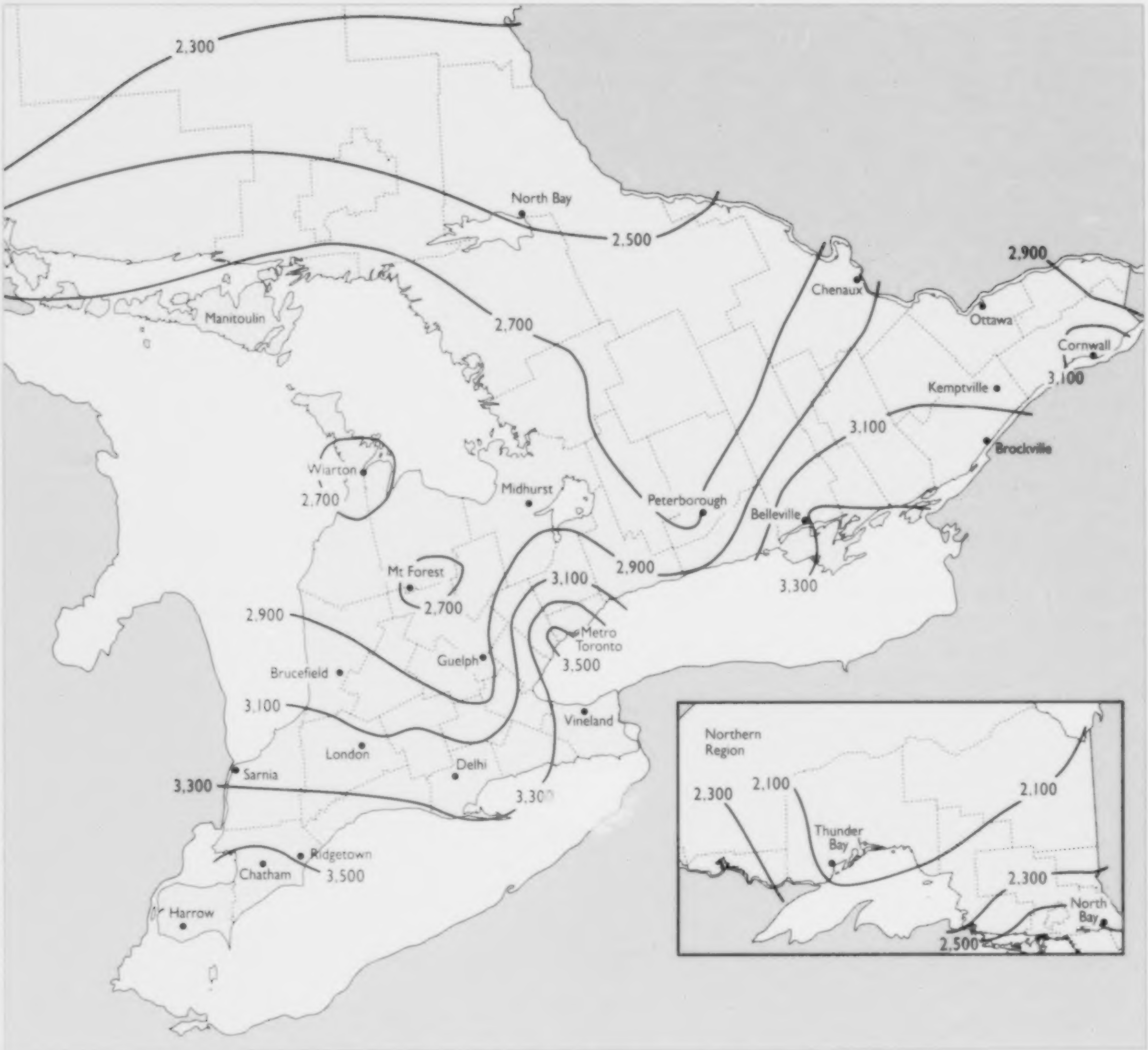

2,300
North Bay
2,500
2,900
Manitoulin
2,700
Chenaux
Ottawa
Cornwall
3,100
Kemptville
3,100
Brockville
Wiarton
2,700
Midhurst
Peterborough
Belleville
2,900
Mt Forest
2,700
3,100
3,300
2,900
Metro Toronto
3,500
Guelph
Brucefield
3,100
Vineland
London
Delhi
Sarnia
3,300
3,300
Ridgetown
Chatham
3,500
Harrow
Northern Region
2,300
2,100
Thunder Bay
2,100
2,300
North Bay
2,500

Figure 1–1. Crop Heat Units (CHU-M1) Available for Corn Production
This map is based on weather data from 1971–2000 with a common season start date across the province of May 1.
Source: Weather Innovations Inc. (WIN)

Selecting the Most Profitable Hybrids

Hybrid selection is probably the single most important management decision in determining cropping profitability. Corn hybrids with superior yield potential have been continuously introduced into the market place over the past 40 years. Yield increases of approximately 1.5% per year have been occurring. To remain competitive, growers must introduce new hybrids to their acreage on a regular basis. The following are a few key considerations intended as general guidelines. Fine-tuning hybrid selection for an individual farm should be done in consultation with seed company representatives.

Maturity and CHU-M1

Using crop heat unit ratings, select hybrids that will reach maturity (black layer) before season-ending frosts traditionally occur in your area. Figure 1–1, *Crop Heat Units (CHU-M1) Available for Corn Production*, this page, or farm records will provide the heat units normally accumulated in a given area.

Highest Yield

In any given hybrid performance trial, there may be a 1.9–2.5 t/ha (30–40 bu/acre) difference in yield between the highest- and lowest-yielding hybrids. This emphasizes the importance of obtaining reliable information on hybrid yield potential and adaptability. Growers must be able to sort through information from two main sources: performance trial data and strip trial data.

The Ontario Corn Committee (OCC) conducts corn hybrid performance trials each year across the province. These performance trials include the majority of available hybrids. Generally, these trials are set up so that a given set of hybrids, for a certain heat unit range, are tested at three to four locations. These trials give a good indication of yield potential but because they are limited to a few locations, do not adequately evaluate hybrid adaptability over a wide range of conditions. For this sort of data, growers need to turn to strip trials that are conducted on a larger number of sites across a wide range of environments. Seed companies usually summarize these strip trials.

Many growers find it valuable to have a corn hybrid strip trial on their own farm. This allows new, high-yield potential hybrids to be tested against those proven performers in the farming practice. However, it is important to remember that reliable hybrid selections require more than one test site even if that site is on the grower's own farm. Growers should look for 2-year data that originate from many sites (preferably more than 30) before making decisions about hybrids that will be planted on a significant portion of their acreage.

Never purchase a corn hybrid without consulting performance data.

The Ontario Corn Committee publishes the *Hybrid Performance Trial Report* each December. This information is also available at the Ontario Corn Producers website at www.ontariocorn.org.

Workhorses vs. Racehorses

Corn hybrids are often classified as "workhorses" or "racehorses." Hybrids that produce above-average yield under good conditions but perform below average under poor conditions are considered racehorses, while those that have relatively consistent yields in both low- and high-yielding conditions are considered workhorses. Most hybrids that are considered to be variable performers (racehorses) have specific defects that cause them to yield lower than average when exposed to certain conditions. Growers can avoid some of the risk associated with hybrid selection by taking time to find out as much as possible about a hybrid's past performance. Select hybrids that complement each other because they have different specific weaknesses. For example, when selecting two full-season hybrids with high yield potential for earliest planting, ensure that they don't both score low for stalk strength.

Standability

Select hybrids that have suitable maturity ratings and outstanding yield potential. A further selection based on hybrid standability rating is recommended. This trait is particularly important where significant field drying is expected. If drying facilities are available on the farm and harvesting at relatively high moisture levels (>26%) is an option, standability may be less critical. Traits associated with improved hybrid standability include resistance to stalk rot and leaf blights, genetic stalk strength (a thick stalk rind), short plant height, lower ear placement and high late-season plant health.

One of the most significant advancements in improved standability has been the introduction of Bt hybrids that are resistant to European corn borer. On a provincial average, Bt hybrids have generally resulted in enough yield increase over their non-Bt counterparts to pay for the additional cost of the Bt seed. Corn grown in areas of the province where corn borer pressure is traditionally high and where corn is being planted earlier or later than the majority of the surrounding corn often benefit significantly from having the Bt gene.

For further information on European corn borer management using Bt hybrids, see *European Corn Borer*, on page 202.

Harvest Moistures and Drying Costs

Hybrid selection may also be influenced by target harvest moistures. In situations where corn is stored as high moisture grain (e.g., 28%), growers have more opportunity to maximize returns by growing full-season, high-yielding hybrids. If corn is dried for storage, evaluate the impact that high harvest moistures may have on net returns. For example, any potential gains in net returns from a hybrid that yields 0.31 t/ha (5 bu/acre) greater than another should be balanced against increased drying charges. OCC performance trial data have shown that when corn is planted early, aggressive hybrid selection (i.e., full-season and beyond) often results in yield advantages over shorter-season hybrids that more than compensate for increased drying costs.

Table 1–14. Recommended Dates to Switch From Full-Season Hybrids Across Various Heat Unit Zones

Heat Unit Zone (CHU-M1)	Switch Date
>3,200+	May 30–early June
2800–3,200	May 20–25
< 2,800	May 15–20

Source: Adapted from R.Iragavarapu. *Basing Hybrid Maturity on Long-Term Data.* Pioneer Hi-Bred Ltd.

Selecting Hybrids for Silage

When choosing hybrids specifically for whole-plant silage, a yield advantage can usually be obtained by selecting hybrids rated 100–200 heat units higher than those selected for grain. Select hybrids for high silage yields with improved digestible energy. Silage-only and dual-purpose corn hybrids are available on the market. Dual-purpose hybrids may provide some flexibility where grain harvest needs to be an option, such as when the silo is full.

Without sufficient independent data, it is very difficult to compare and select corn silage hybrids between companies. Choose top hybrids that have strong ratings for silage yield and quality. Various models are used to compare the economic value of corn silage hybrids. The University of Wisconsin has developed "milk per acre" and "milk per ton" calculations using their Milk 2006 model to combine the traits of silage yield, digestibility, fibre, starch, crude protein and intake potential into single measures. Milk per ton measures quality, while milk per acre combines yield and quality.

Switching to Shorter-Season Hybrids

Field conditions may delay planting and necessitate switching to less than full-season hybrids. Factors to consider in this decision include yield potential of shorter-season hybrids, test weight concerns, drying costs and late-season harvesting capabilities.

Grain corn obtains 90% of its total grain weight by one-half milk line, a maturity stage that even late-planted, full-season hybrids reach in most years. Switching to shorter-season hybrids may be a reasonable alternative from a grain yield perspective if earlier hybrids can produce within 10% of the full-season hybrid's yield. Generally, this is a more favourable proposition in longer-season areas.

Growing 3,000 CHU-M1 hybrids as the full-season selections allows for switching to hybrids that are 100–150 heat units less without sacrificing excessive yield. If the full-season hybrids are in the 2,800 CHU-M1 range, the odds of dropping to a hybrid 100 heat units less without giving up more than 10% yield are low.

Table 1–15. Grain Corn Test Weights and Potential Dockage

Grade[1]	Test Weight Minimum (kg/ha)	Test Weight Minimum (lb/bu)	Potential Dockage $/t
1	68.0	55.6	.00
2	66.0	54.1	.00
3	64.0	52.6	0.79
4	62.0	51.0	3.94
5	58.0	47.7	7.88

[1] Based on 2001 market. Potential dockage may vary considerably depending on year and location.

Extensive research across the northern corn belt defines the optimal date when producers should switch away from full-season hybrids. Some of this data is summarized in Table 1–14, *Recommended Dates to Switch From Full-Season Hybrids Across Various Heat Unit Zones*, this page. This collection of long-term data took into account yields for hybrids of various maturity ratings as well as deductions for test weight and drying. The switch date indicates the planting date when earlier-maturing hybrids surpass full-season hybrids in terms of net returns (gross returns less drying and test weight deductions).

Growing hybrids with a range in maturity provides some buffer against both silking time stresses and end-of-season risks. However, making significant shifts to earlier hybrids should be reserved in the Southwest (>3,200 CHU-M1) until May 30–June 1; in the mid-maturity corn growing areas (2,800–3,200 CHU-M1) until May 20–25 and in the shorter-season areas (<2,800 CHU-M1) until May 15–20.

A general rule has been to reduce hybrid maturity by 100 CHUs for every week that planting is delayed beyond the cut-off date for full-season hybrids.

Test Weight Concerns

Lower test weights often result if end-of-season frosts occur before late-planted corn has reached maturity (black layer). Consider test weight potential when selecting hybrids for planting in a late spring. Potential dockage from delivering lower bushel weight corn to an elevator or end user is shown in Table 1–15, *Grain Corn Test Weights and Potential Dockage*, this page.

Table 1–16. Seed Spacing to Achieve Various Populations

		Row Width: cm (in.)													
Final plants/ha	Final plants/acre	38	(15)	51	(20)	56	(22)	71	(28)	76	(30)	91	(36)	97	(38)
		Distance between in-row corn plants in cm (in.)													
54,300	22,000	48	(19.0)	36	(14.3)	33	(13.0)	26	(10.2)	24	(9.5)	20	(7.9)	19	(7.5)
59,300	24,000	44	(17.4)	33	(13.1)	30	(11.9)	24	(9.3)	22	(8.7)	18	(7.2)	18	(6.9)
64,200	26,000	41	(16.1)	31	(12.1)	28	(11.0)	22	(8.6)	20	(8.1)	17	(6.7)	16	(6.4)
69,200	28,000	38	(14.9)	29	(11.2)	26	(10.2)	20	(8.0)	19	(7.5)	16	(6.2)	15	(5.9)
74,100	30,000	35	(13.9)	27	(10.5)	24	(9.5)	19	(7.5)	18	(7.0)	15	(5.8)	14	(5.5)
79,000	32,000	33	(13.1)	25	(9.8)	23	(8.9)	18	(7.0)	17	(6.6)	14	(5.4)	13	(5.2)
84,000	34,000	31	(12.3)	23	(9.2)	21	(8.4)	17	(6.6)	16	(6.1)	13	(5.1)	12	(4.9)

1 ha = 2.47 acre; 1 cm = 0.39 in.

Farming operations that handle and feed all of their own corn may be unaffected by test weight concerns and may choose to remain with full-season hybrids longer into the planting season. Experience and research from 1992 and 2000 indicated there was little or no correlation between test weight and livestock feed value. Producers who deliver all their corn to elevators or processors may want to switch to earlier hybrids to increase the potential for suitable test weights at harvest. Producers in shorter-season areas who fear significant yield losses by switching to earlier-maturing hybrids may consider staying with full-season hybrids but switching to hybrids that have higher test weight scores.

Harvesting

Sticking with high-yielding, later-maturing hybrids may present some logistical harvest issues. Fields planted to potentially delayed hybrids should be well-drained and have good load-bearing capacities to facilitate late-season harvesting in less than ideal conditions. Avoid planting later-maturing hybrids in areas of the province that are more prone to November snow. The snow adheres to leaves and husks, making harvest impossible until a change in the weather allows the snow to melt from the corn plants.

Planting

Seeding Date

The best yields are usually obtained from corn planted in late April and the first half of May, because the crop is able to use the full growing season. Early planting also results in earlier maturity in the fall, reducing the risk of damage from an early fall frost or adverse weather at harvest. The optimum planting date is on or before May 7 in Southwestern Ontario and May 10 in Central and Eastern Ontario. Delaying planting past the optimum date can result in yield reductions averaging about 1% per day of delay in May. As planting dates become later, the rate of yield loss per day of delay increases. Yield losses for the first 3 weeks of June are about 2% per day of delay in longer season regions of Ontario (>3,050 CHU-M1) and 3% per day of delay in shorter season regions.

Depending on the total number of days required to plant the farm's entire corn acreage, it is generally necessary to start planting corn well before the optimum date. Producers wanting to plant corn significantly earlier than optimum dates (i.e., April 15–25) should remember that soil temperatures need to reach a minimum of 10°C before germination and emergence will occur. The average daily temperature is estimated by taking a temperature measurement around 11:30 AM using a 10-cm (4-in.) soil thermometer. If average soil temperatures are at or beyond 10°C, the soil conditions are favourable and the weather forecast is predicting average to above-average temperatures, then early planting of at least a portion of the corn crop is recommended. After April 26 (May 1 in areas receiving less than 3,000 CHU-M1), it is generally advisable to pay less attention to soil temperature and to plant as soil moisture conditions permit. Generally, the loss of potential yield associated with planting 2–3 weeks before optimum planting date is less than the loss associated with planting 2–3 weeks after the optimum planting date.

Population

The plant populations discussed in this section are suggested final plant stands (see Table 1–16, *Seed Spacing to Achieve Various Populations*, this page). Since not all seeds emerge, it is necessary to seed at slightly higher rates. When planting early in the season or when the soil is cold, a seeding rate 10% higher than the desired final stand is recommended. When soils are warmer, an adjustment of 5% is sufficient.

In Ontario, corn has commonly been grown at populations of 64,000–74,000 plants/ha (26,000– 30,000 plants/acre). These populations can produce good yields over a wide range of growing conditions without excessive lodging. In recent years, hybrids have been developed that tolerate higher plant densities without excessive lodging or barrenness. Research has shown that when old and new hybrids are grown side by side under very low populations, they yield almost identically. Higher yield responses occur as newer hybrids are grown at higher densities. Much of the historical yield improvement has resulted from developing hybrids that excel under higher densities. Some of the most recent hybrids report having economically optimum populations of 74,000–86,000 plants/ha (30,000–35,000 plants/acre). Refer to seed company data to fine-tune hybrid management and planting density decisions.

On drought-susceptible fields where water availability, not light interception, is almost always the yield-limiting factor, the yield potential of increased seeding rates may not always cover the cost of higher density seedings. In these situations, adjusting populations downward can achieve some savings. Research from the U.S. indicates that the optimum final plant population in the Midwest Corn Belt is 67,000 plants/ha (27,160 plants/acre). This research predicts that for every 0.94 t/ha (15 bu/acre) increase in a field's (or parts of field's) yield potential, economically optimal populations increased by 1,112 plants/ha (450 plants/acre).

In Ontario, it is common to aim for higher average final stands than in the U.S. Midwest. The most productive fields should be near the upper end of the plant population range for the hybrids being planted. In shorter-season areas of the province, where smaller-stature hybrids are grown, populations may be under even more pressure to remain high to maximize light interception and optimize yields. Yield increases from increased plant densities have generally been lowest in the warmer regions of Ontario (over 3,200 CHU-M1 heat units).

Since lodging is of less concern for whole-plant corn silage, higher plant populations (10%) than those for grain corn have often been recommended. Research from Cornell University indicates that for silage growers who had been adopting ultra-high populations — 111,200–123,500 plants/ha (45,000–50,000 plants/acre), there were no advantages for any of the hybrids tested to having stands of more than 86,500 plants/ha (35,000 plants/acre). The research predicted that as hybrid populations increased, silage digestibility declined. There is increasing genetic diversity among silage hybrids suggesting that optimum populations may be very hybrid specific.

Planting Depth

The first rule of corn planting depth is to plant securely into moisture. However, a few other considerations allow for some fine-tuning of planting depth. Overly shallow planting of corn (less than 3 cm or 1.25 in. deep), even into moisture, may lead to less favourable positioning of the growing point and first nodal roots. This may lead to rootless corn syndrome in some cases and predisposes the seed to greater injury from herbicides. Coarse-textured soils that dry rapidly at the surface will also be more prone to poor root establishment with shallow plantings.

The general rule for planting depth is 3.75 cm (1.5 in.), but ensure seed is planted into moisture.

In contrast, planting deeper at 5–8 cm (2–3 in.), especially early in the planting season when soils are cold, can significantly delay emergence compared to planting at depths of 3–5 cm (1¼–2 in.). In conditions where soil temperatures are lower (i.e., early season, cool season, no-till, etc.) and when soil moisture levels are adequate, target planting depths to around 3.75 cm (1½ in.). As the planting season progresses and as soils warm and dry, ensure that the corn seed is placed firmly into moisture. When planting is extended and soils warm, planting at depths of 7.5 cm (3 in.) in order to find moisture is often less risky than planting shallower and hoping for rain.

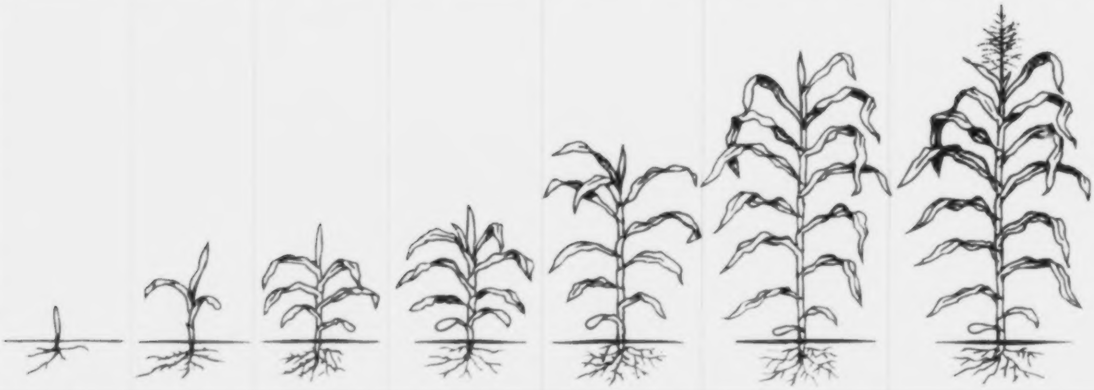
Corn Development

The vegetative and reproductive growth stages in corn are described in Table 1–17, *Vegetative Growth Stages in Corn*, next page, and Table 1–18, *Reproductive Growth Stages in Corn*, on page 15.

CHU Season-Ending Dates

The end of the growing season is defined as the first occurrence of a killing frost (–2°C), or the date when the daily average temperature has historically (30-year normals) fallen below 12°C. In the 30-year data used for CHU calculations, the season is terminated approximately 10% of the time by an occurrence of –2°C. This approach is identical for the CHU (traditional) and CHU-M1 (May 1 start date) calculations (see *Revised Ontario Crop Heat Units*, on page 8).

Table 1–17. Vegetative Growth Stages in Corn



Stage	VE	V1	V4	V6	V8	V12	VT
Leaf Collars[1]	0	1	4	6	8	12	(varies)
Leaf Tips	1	3	7	10	11	15	—
Leaf Over	0	2	6	8	10	14	—
CHUs Required[2]	180	330	630	780	930	1,170	1,310
Target Date[3]	May 14	May 26	June 12	June 20	June 28	July 2	July 21
Notes	• Emergence. • Days to emerge most often ranges from 6–21 days. • Uniform emergence essential to high yields. • Look for poor germination caused by chafer, wireworms, seedcorn maggot, seedcorn beetle, slugs, black cutworm.	• Start of critical weed-free period. • Growing point below ground. • Ensure herbicide selection is safe for crop stage.	• Ear initiation. • Growing point below ground. • Expansion of nodal root system will soon completely replace seminal root system. • Risk from cutworm and flea beetle damage has passed.	• End of critical weed-free period. • Lower leaves (1–4) dry up, may not be visible • Growing point at or above ground; more susceptible to frost injury. • Initiated ears and tassel now visible upon plant dissection.	• Side-dressing nitrogen and inter-row cultivation beyond this point pose threat of root pruning. • Beginning rapid stem elongation. • Risk from slug damage has passed.	• Crop becomes increasingly sensitive to yield reduction by heat or drought. • Size of ear and number of potential kernels being established.	• Tassel emerges. • Pollen shed begins 2–3 days prior to silk emergence. • Pollen viability reduced by drought and high temperatures. • Scout for corn leaf aphids, corn rootworm adults and goosenecking caused by rootworm larva.

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[1] See *Corn Leaf Stages*, opposite page, for a description of the methodologies of corn leaf counting.

[2] Approximate CHUs required to reach various stages of corn development.

[3] Estimated date to reach various stages of development based on long-term heat unit accumulations for an average 2,800-CHU-M1 region and anticipating a May 1 planting date.

Table 1–18. Reproductive Growth Stages in Corn

Description	Silks emerge from husks at tip of ear.	Kernels are white, filled with clear fluid and distinct from surrounding cob material.	Kernels begin to have yellow colour. Inner fluid is milky white.	Milky inner fluid becomes thicker and pasty. Outer edges of kernels become firmer. Some dents appear.	Majority of kernels are dented. Hard white layer of starch evident at top of kernel (milk line).	Hard starch layer evident from top to bottom of kernel. Black layer forms at base of kernel.
R Stage	R1 – Silking	R2 – Blister	R3 – Milk	R4 – Dough	R5 – Dent	R6 – Maturity
CHUs Required[1]	1,480	1,825	2,000	2,165	2,475	2,800
Target Date[2]	July 23	Aug. 6	Aug. 14	Aug. 22	Sept. 6	Sept. 26
Kernel Moisture	NA[3]	85%	80%	70%	55%	30%–35%
Notes	• Pollination requires 3–7 days. • Silks continue to elongate until fertilized. • Environmental stresses very detrimental to yield. • Begin scouting for ear insect pests (corn earworm, fall armyworm).	• Kernels beginning dry matter accumulation. • Relocation of nutrients from the leaves and stem to the ear begins. • Firing of lower leaves may become evident.	• Rapid grain filling period. • Good plant health, clear skies and active photosynthesis add to kernel size and test weight.	• Top of kernel begins to firm up. • Killing frost may cause yield losses of 25%–40%. • Begin to assess ear rot incidence.	• Milk line advances toward tip as crop matures. • Whole plant moistures suitable for silage harvest. • 90% of grain yield reached by one-half milk line. • Examine fields for lodging, ear drop and stalk rots. If high, consider harvesting early.	• Physiological maturity. • Kernels have achieved maximum dry weight. • Moisture loss from kernels still required for suitable threshing.

[1] Approximate CHUs required to reach various stages of corn development.

[2] Estimated date to reach various stages of development based on long-term heat unit accumulations for an average 2,800-CHU-M1 region and anticipating a May 1 planting date.

[3] NA: not available, kernels not formed until after pollination.

Corn Leaf Stages

Counting the leaves on a corn plant sounds like an easy task, but there are a few complications that can cause miscounting. It is important to know which leaf-counting method is being referred to on pesticide labels or in other production information.

Table 1–19, *Comparative Growth Stages*, this page, shows comparative growth stages using different methods of counting leaves.

There are several methods used to count corn leaves:

- The **leaf-tip method** counts all leaves, including any leaf tip that has emerged from the whorl at the top of the plant.
- The **leaf-over method** only counts those leaves that are fully emerged and are arched over with the next leaf visible in the whorl but standing straight up.
- The **leaf-collar method,** used extensively in the U.S., refers to the leaf collar being visible. The leaf collar is the light green-to-whitish band that separates the leaf blade from the leaf sheath, which wraps around the stem. The stages for corn are referred to as V1, V2, V3, etc., where the V3 stage is a plant with three collars visible.

Table 1–19. Comparative Growth Stages

Leaf Tip	Leaf Over	Leaf Collar	Standing Height (cm)	Leaf Extended (cm)
3	2	1	5–6	5–11
5–6	4	3	9–17	16–25
7–8	6	4–5	18–33	29–46
9–10	8	5–6	36–54	54–77
12	10	8	58–85	86–112
14–15	12	10	99–114	121–149

Source: OMAFRA Publication 75, *Guide to Weed Control.*

Table 1–20. Corn Yield Response to Plant Spacing and Emergence Variability

Research was conducted at Elora and Woodstock, 2000–01.

	Emergence Delay		
	Uniform	**2-leaves (1 in 6)**	**4-leaves (1 in 6)**
Plant Spacing	**% Yield**[1]		
uniform	100	95	91
double (33% of plants)	99	95	90
triple (50% of plants)	98	94	90

Source: Lue, Tollenaar, Stewart, Deen, University of Guelph.

[1] Expressed as a percent of the uniform spacing and emergence treatment.

Uniformity of Emergence

Uniform seeding depth is a critical factor in achieving uniform emergence (Plate 7 on page 280). Uneven emergence affects crop performance, because competition from larger, early-emerging plants reduces the yield potential of smaller, later-emerging plants. Research indicates that yields can be reduced by 5% when half the stand suffers from a 7-day delay in emergence and by 12% when half the population experiences a 2-week delay. Table 1–20, *Corn Yield Response to Plant Spacing and Emergence Variability*, this page, shows the results of a University of Guelph study that examined the relative impact of emergence and in-row spacing variability on corn yield. If one of six plants (17%) had an emergence delay equal to two leaf stages (about 12 days), then overall yield reduction was 4%–5%. If one of six plants had emergence delays equal to four leaf stages (about 21 days), then overall yield was reduced by 8%. The sizes of yield reductions associated with delayed emergence were not significantly affected by the spacing variability of the stand (doubles and misses) within the corn row.

Uniformity of Spacing

It is widely believed that uniform in-row plant spacing is necessary to produce top corn yields. However, a recent study conducted by the University of Guelph challenges the notion that significant increases in row plant spacing variability results in large yield losses. The relative yields shown in Table 1–20 indicate that yield losses are about 1% if the stand contains two out of six plants (33%) that are clustered as doubles and 2% if three out of six plants (50%) are clustered as triples. Doubles in this study were defined as two plants spaced about 3 cm (1⅓ in.) apart situated next to a gap of about 38 cm (15 in.) and triples were three plants spaced 3 cm from each other next to a gap of 58 cm (23 in.). This study clearly demonstrated that even if half the stand were clustered as triples, that yield losses were minimal when overall population is not affected and emergence is uniform. The lower individual yields of corn plants that were part of clusters were almost completely compensated for by higher yields of single plants that were situated next to the gaps.

Recent University of Guelph research suggests that a 2.5-cm (1-in.) increase in plant stand standard deviation decreased yield by less than 0.08 t/ha (1.3 bu/acre), assuming equal plant populations. These results were consistent with earlier research conducted in Ontario during the late 1970s and in Wisconsin from 1999 to 2001. It should be noted that there are some studies that suggest significant yield losses associated with increasing plant stand variability. Dr. Bob Nielsen (Purdue University, Indiana) has reported that every additional 2.5 cm (1 in.) of standard deviation over 5 cm (2 in.) decreases yields by 160 kg/ha (2.5 bu/acre).

Results of a 1998–2000 survey of 127 Wisconsin commercial corn fields with an average plant population of 73,500 plants/ha (29,750 plants/acre) suggested that plant spacing standard deviation averaged 8.4 cm (3⅓ in.) with 95% of fields having standard deviations that were less than 11.7 cm (4⅔ in.). The results of 24 research trials conducted along with the Wisconsin plant variability survey concluded that significant yield reductions begin to occur only when corn plant standard deviations exceed 12 cm (4¾ in.). This supports the Ontario research findings shown in Table 1–20 that suggest minimal yield impact of uneven plant spacing. Generally, within the range of plant spacing variability typically found in most Ontario corn fields that are at the target population, the reduction in yield potential due to plant stand variability is likely small.

Poor planter maintenance or high planting speeds are often identified as contributing to poor within-row spacing uniformity. Research conducted in Illinois (Table 1–21, *Effect of Planting Speed on Spacing Standard Deviation, Population and Corn Yield*, opposite page) illustrated that with properly maintained planters, high planting speeds and slight variations in spacing uniformity had no impact on yield. Similar results were also observed in a University of Guelph study where increasing planting speed from 6.5–12 km/h resulted in a 1–2.5 cm (½–1 in.) increase in plant spacing and no effect on corn yield in conventional tillage systems. However, the higher planting speed did decrease no-till corn yield by 0.2 t/ha (3.1 bu/acre). This suggests that slower planting speeds may be necessary for planting equipment to uniformly place seed in seedbeds with more variable soil and/or surface residue conditions that are typical of reduced or no-till planting systems.

Planting Equipment and Maintenance

Choice of planting equipment can have an impact on corn yield potential. Interest has increased in recent years in

Table 1–21. Effect of Planting Speed on Spacing Standard Deviation, Population and Corn Yield
(Average of 11 Illinois trials, 1994–96)

Planting Speed km/h	Standard Deviation[1] cm (in.)	Population plants/ha (plants/acre)	Yield t/ha (bu/acre)
5	7.3 (2.87)	67,290 (27,231)	9.57 (152.5)
8	7.6 (2.99)	67,640 (27,373)	9.55 (152.2)
11.3	8.2 (3.22)	66,700 (26,996)	9.61 (153.1)

Source: E. Nafziger, Univ. of Illinois and H. Brown.

[1] An absolutely perfect stand, where every plant is exactly 18 cm (7¼ in.) from its neighbour, would have a standard deviation of zero. If plants on average varied plus or minus 5 cm (2 in.) from the desired 18 cm (7¼ in.), then the standard deviation would be 5 cm (2 in.).

Ontario for use of lower-cost planting systems, such as air seeders, that could potentially plant all crops. Table 1–22, *Effect of Planter Type on Corn Spacing Variability*, this page, contains the results of a study that evaluated the performance of three planters in conventional and no-till systems. Use of the air seeder resulted in greater plant spacing variability, delays in emergence and lower corn yields compared to use of the row crop planters. The yield reduction associated with the air seeder was larger in the no-till system, because the simpler planter design of the air seeder was not as capable as the row crop planters at maintaining uniform seeding depth and consistent seed furrow closure in the no-till system. There appeared to be a slight yield advantage with the newer row crop planter over the older model, suggesting that advances in planter design that result in more consistent seed placement increase corn yield potential.

Uniformity and timing of emergence, along with achieving target populations, generally have a greater impact on corn yield than uniformity of corn plant spacing. Planter maintenance and choice of attachments (i.e., coulters and residue row cleaners) should focus on achieving consistent seed placement and the creation of in-row seedbed conditions that ensure rapid uniform emergence. It is important to ensure that the planter is operating level and that all discs, depth-gauging wheels and seed-firming devices are up to specifications, aligned and operating at the correct depth or pressure.

Pre-planting management may also play a critical role in emergence uniformity. If the field is left too uneven, if residue is bunched, or if surface compaction has not been uniformly alleviated, even the most carefully prepared corn planter may not be able to consistently place seed and create in-row seedbed conditions that ensure rapid uniform emergence.

Table 1–22. Effect of Planter Type on Corn Spacing Variability

Tillage Planter Type	Spacing Deviation (in.)	50% Emergence (days)	Grain Yield (bu/acre)
Moldboard			
Vacuum meter[1]	3.4	10.1	123
Finger-pickup[2]	4.1	10.4	119
Air seeder[3]	7.5	11.6	117
No-Till			
Vacuum meter[1]	3.1	11.8	114
Finger-pickup[2]	4.4	11.7	110
Air seeder[3]	8.1	13.5	100

Source: Liu, Tollenaar, Stewart, Deen; University of Guelph. Research was conducted at Elora and Woodstock, 2000–01.

Planter Descriptions:

[1] The vacuum meter was a John Deere 1750 MaxEmerge Plus row-crop planter manufactured in 1998 and equipped with a double-disk opener system, 2.5 cm-wide, angled closing wheels, fingered residue removers attached in front of the furrow opener, three coulters set at a 10–15-cm depth, and seed firmers.

[2] The finger-pickup planter was a John Deere 7000 row-crop planter manufactured in 1986 with similar components as the vacuum meter planter, except for the absence of seed firmers.

[3] The air seeder was a Gandy Orbit-Air 6224 air seeder manufactured in 1990 and equipped with single-disc openers and a single, angled closing wheel. The air seeder did not have residue removers, coulters, or seed firmers.

When walking corn fields keep the following in mind:

- Plants that emerge late, so that they are one or two leaves behind neighbouring plants, are likely to achieve a lower yield relative to uniformly emerged stands and may even yield less than later-planted but uniformly emerged corn.
- Relatively small investments in time and/or money for planter adjustments, such as installing new opener discs, levelling the planter, properly adjusting seed-firming wheels and proper seed depth placement, can significantly increase yield and returns.

Row Widths

Narrow Rows

By the mid-1990s, research conducted at various locations across the northern Corn Belt and Southern Ontario indicated significant yield advantages could be expected from narrowing corn rows from the traditional 76–96 cm (30–38 in.) down to row widths of 38–60 cm (15–24 in.). Results showed that narrow row advantages would be greater in more northerly latitudes, compared to results coming from the mid-to-southern portions of the Corn Belt. Most Ontario producers who converted

Table 1–23. Expected Grain Yield Due to Various Planting Dates and Populations

	Plant Population (%)								
Planting Date	25,000 /ha 10,000/acre	31,000/ha 12,500/acre	37,000/ha 15,000/acre	43,000/ha 17,500/acre	49,000/ha 20,000/acre	56,000/ha 22,500/acre	62,000/ha 25,000/acre	68,000/ha 27,500/acre	74,000/ha 30,000/acre
April 20	62	70	78	82	86	90	92	94	94
April 25	65	73	79	84	89	92	95	97	97
April 30	67	74	81	86	91	94	97	98	99
May 4	68	75	82	87	92	95	98	99	100
May 9	68	75	82	87	92	95	98	99	100
May 14	67	75	81	86	91	94	97	99	98
May 19	65	73	79	85	89	93	95	97	97
May 24	63	70	76	82	86	90	92	94	95
May 29	59	68	73	78	83	86	89	90	91
June 3	54	62	68	74	78	82	84	86	86
June 8	49	56	63	68	73	76	79	80	81

Adapted from University of Illinois data, E.D. Nafziger. 1994. *Journal of Production Agriculture*. Original data from Illinois was shifted 10 days later to reflect optimal planting dates in Ontario.

Example: A field is planted on May 4 with an expected plant population of 62,000 plants/ha (25,000 plants/acre). By the end of the month, the stand is reduced to 31,000 plants/ha (12,500 plants/acre) but uniform in size and plant distribution. The table would suggest that the expected yield for a final plant stand of 31,000 planted on May 4 would be 75% (a 50% reduction from the targeted population). By planting on May 29 at the same population (62,000), a yield of 89% can be expected. In this case, the cost of replanting may be recovered and therefore justified. Interpolate the data for planting dates or plant stands that differ from the listed values.

to narrow-row production systems targeted 50-cm (20-in.) row spacing and anticipated paying for planter and corn header conversions with an expected yield boost of 3%–8%. More recently, studies conducted in Ontario by the University of Guelph and Pioneer Hi-Bred Ltd. have shown little to no yield advantage with 38-cm (15-in.) or 50-cm (20-in.) rows compared to 76-cm (30-in.) rows. The fundamental reason for moving to narrower rows is to enhance light interception. It appears that the total light interception once the canopy has fully developed is no greater in narrow rows than in wide rows. The perceived yield advantage of narrow rows must come from earlier canopy closure and greater light interception in the late-June to early-July period.

In addition, research did not indicate that there were specific hybrids particularly adapted to narrow rows. High plant populations within narrow rows often boosted yields, but yields were often increased on traditional row widths as well. Yield improvements may be sporadic and the justification of equipment costs may depend on other factors such as use of the narrow row planter for other crops (e.g., dry edible beans), numbers of acres to be planted and costs of equipment conversions. There is also the increased risk for stalk rots in narrow row systems.

Replant Decisions

There is no simple formula to aid in replant decisions, so each case must be dealt with individually. When contemplating a replant decision, consider the original planting date, target plant population, actual population, uniformity of plant size, distribution following damage, possible replanting date and cost of replanting (seed, fungicides/insecticides, fuel, etc).

The actual plant population can be estimated by counting the number of plants in a length of row that is equal to ¹⁄₁₀₀₀ of an acre (see Appendix J, *Plant Populations at Various Row Widths*, on page 268). This should be replicated at least five times per 10 ha (25 acre) in separate parts of the field. Calculate the average of these samples and then multiply the average by 1,000.

It is important when taking stand counts to observe the uniformity, plant size and distribution of the plants in the rows. How do the stand, plant size and distribution vary? Yields can be reduced by 2% if the stand has several 30–90-cm (12–36-in.) gaps. If the gaps are larger — 1.25–2 m (4–6 ft) — expect a 5%–6% reduction in yield when compared to a uniform stand. Yield reductions will be greater with more numerous and longer gaps between plants within the row.

Table 1–23, *Expected Grain Yield Due to Various Planting Dates and Populations*, this page, shows the effect of planting date and plant population on final grain yield. Yields are based on stands that are normal in terms of uniformity of plant size and distribution. Grain yields for varying dates and populations are expressed as a percentage of the yield obtained at the optimum planting date and population: 64,200–76,200 plants/ha (26,000–30,000 plants/acre). Results will vary depending on location, environmental conditions, hybrid and other factors.

The availability of early-maturing hybrids with good yield potential and the cost of replanting are important factors in the replant decision. Consider whether the herbicide program allows for a switch to soybeans. If not, is a reapplication of corn herbicides required? What is the condition and health of the remaining crop? Before replanting, determine whether the conditions that caused the problem in the first place still exist (soil conditions, disease, insects, herbicide injury). If an insect or disease problem was the culprit, factor in the cost of an insecticide and/or fungicide treatment.

Fertility Management

Nitrogen

Corn responds well to nitrogen, so adequate availability of nitrogen is critical to profitable corn production. However, excess nitrogen adds unnecessary expense and increases the risk of nitrate movement to groundwater.

Nitrogen deficiency first appears on the lower leaves, manifested as yellowing, beginning at the tip of the leaf and proceeding down the midrib (Plate 1 on page 279). Eventually, the yellow areas will turn brown and die.

In young plants, yield loss will occur long before nitrogen deficiency symptoms appear, so yellowing is not a reliable indicator of the need for nitrogen fertilizers.

Two methods can be used to determine optimum nitrogen rates:

- the nitrate-nitrogen soil test
- general recommendations based on expected yield, soil type, previous crop, location and fertilizer price adjusted for legumes, manure or other sources of organic nitrogen

> It is common to see symptoms of nitrogen deficiency in the lower leaves as the plants near maturity, even when there is adequate nitrogen for optimum yield.

Nitrate-Nitrogen Soil Test

Soils can vary greatly in their ability to supply nitrogen. The amount of nitrate-nitrogen present in the soil at planting time, or just before side-dress, can be a useful indicator of a soil's capacity to supply nitrogen. Use of the soil test for nitrate-nitrogen should result in a more efficient and profitable use of nitrogen as well as a reduction in the risk of nitrate movement into groundwater.

Many of the factors included in the general recommendations will influence the soil nitrate levels, so the recommendations for the nitrate-nitrogen soil test should be viewed as separate from the general nitrogen recommendations. Research is ongoing to find methods to incorporate the soil test into the general recommendations as an adjustment.

Time of Sampling

The nitrogen recommendations based on the soil test for nitrate-nitrogen were developed using samples that were taken within 5 days of planting (before or after). However, this is often an inconvenient time for sampling. Seasonal differences in weather can dramatically change the soil tests at this time of year (see *Where Caution Is Required*, next page). Alternatively, sampling when the corn is 15–30 cm (6–12 in.) tall, before the application of side-dress nitrogen, has increased in popularity. This is referred to as the pre-side-dress nitrogen test (PSNT).

By delaying sampling past the busy planting season, the PSNT allows more time for sampling and receiving results from the laboratory. More importantly, considerable evidence indicates that nitrogen recommendations based on this later sampling time are superior to those based on a planting time sample. This is particularly true when there are organic sources of nitrogen, such as manure or legumes, in the cropping system. PSNT samples taken in June detect nitrate that has mineralized from these organic sources and will more accurately reflect total available nitrogen and fertilizer nitrogen requirements.

Taking the Sample

Nitrates are more mobile than either phosphorus or potassium, so a separate, deeper, soil sample must be taken for the nitrate-nitrogen test. The soil should be sampled to a depth of 30 cm (12 in.). It is important that all cores in a field be taken to the same depth and that the sampling depth be included with the information sent with the sample to the lab.

To ensure that the sample is representative of the field, use a sampling pattern similar to that recommended for the standard soil test, described in *Soil Sampling*, on page 156. Since variations in soil nitrate content can have a large impact on nitrogen fertilizer recommendations, consider sampling more intensively for nitrate than for phosphorus or potassium.

Take separate samples of:

- areas with differences in past management
- areas with distinctly different soil types
- knolls and depressions

Handling the Sample

Place soil cores in a clean plastic pail, crushed by hand and well mixed. Take about 500 gm of soil (1 lb) from the pail and place it in a clean plastic bag or soil sample box.

Microbial action in the sample can change the nitrate content quickly if it is not handled properly. Chill or freeze samples as soon as possible. For shipping, pack samples with insulating material to keep them cool and send them by courier to ensure quick delivery to the lab.

Samples can also be air-dried. Spread the sample in a thin layer on a clean plastic sheet, breaking up any large lumps in the process. It should be dry in 1–2 days, and can be shipped to the lab without any extra precautions. Do not dry the samples in a warm oven, as this can affect the nitrate content.

Where Caution Is Required

Sometimes the fertilizer recommendations based on the nitrate-nitrogen soil test need to be modified.

The nitrogen in manure or legumes applied or plowed down just before sampling will not have converted into nitrates and will not be detected by the soil test. Information will be provided with the test results on how to make appropriate adjustments.

The nitrate-nitrogen soil test has not been adequately evaluated for:

- legumes or manure plowed down in the late summer or fall
- legumes in a no-till system
- soil samples taken prior to planting before the soil has warmed up significantly (i.e., in mid- to late April)

In these circumstances, use the nitrate-nitrogen soil test with caution.

Table 1–24, *Nitrogen Recommendations Based on Nitrate-Nitrogen*, this page, shows the recommended application rates of nitrogen for different levels of soil nitrate-nitrogen for 30-cm (12-in.) deep samples when the nitrogen/corn price ratio is 5. If the price ratio is increased to 7 (i.e., the price of nitrogen fertilizer has increased or the price of corn has decreased), reduce the recommended rates by 20 kg/ha (18 lb/acre) from the rates in this table. See *Price Ratio Adjustment*, in Appendix B, page 259.

Table 1–24. Nitrogen Recommendations Based on Nitrate-Nitrogen

Spring Nitrate Nitrogen[1] in top 30 cm (1 ft)	Pre-Side-Dress Nitrate Nitrogen[2] in top 30 cm (1 ft)	Actual Nitrogen Recommended	
(ppm)	(ppm)	(kg/ha)	(lb/acre)
1	1	211	189
2	3	199	178
3	4	186	166
4	5	173	155
5	7	161	144
6	8	148	132
7	9	135	121
8	10	123	110
9	12	110	98
10	13	97	87
11	14	85	76
12	16	72	64
13	17	59	53
14	18	47	42
15	20	34	30
16	21	21	19
17	22	9	8
18	23	0	0

Conversion Factors

To convert soil test results from kg/ha to ppm for a 30-cm (12-in.) sample, divide kg/ha by 4. For example, if the nitrate-nitrogen concentration of a sample taken from the top 30 cm (12 in.) of soil is 32 kg/ha, the nitrate nitrogen is 32 kg/ha ÷ 4 = 8 ppm.

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[1] Spring nitrate-nitrogen refers to samples taken within 5 days of planting (either before or after).

[2] Pre-side-dress nitrate-nitrogen refers to samples taken when the corn is 15–30 cm (6–12 in.) tall (usually within the first 2 weeks of June).

Adjust rates downward if the preceding crop was a legume sod (see Table 9–7, *Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down*, on page 162). If manure was applied, see Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page 164.

Laboratories

See Appendix C, *Accredited Soil-Testing Laboratories in Ontario*, on page 260, for a list of laboratories that are accredited to analyze soil samples for nitrate-nitrogen.

Corn Nitrogen Rate Worksheet

General Recommended Nitrogen Rates for Corn (Metric)

The figures in this worksheet are based on a review of N response trials from 1961–2004. The fertilizer rates calculated here are designed to produce the highest economic yield when accompanied by good or above-average management. Research shows that higher rates will occasionally produce higher yields, but usually not enough to pay for the additional fertilizer.

A version of the worksheet using Imperial measure, as well as notes that explain each section can be found in Appendix B, *Corn Nitrogen Rate Worksheet (Imperial) With Detailed Explanation*, on page 258.

A. Base N Requirement (choose from Table A)	_____
B. Yield Adjustment (Yield (T/ha) _____ x 13.6) =	+ _____
C. Heat Unit Adjustment Your CHU-M1s = _____ Less – 2,800 Total = _____ x 0.041 =	+ _____
D. Previous Crop Adjustment (Choose from Table D)	– _____
E. Price Ratio (PR) Adjustment for Nitrogen Relative to Corn Price (Choose from Table E)	– _____
F. Total N recommendation (A+B+C–D–E)	= _____
G. Deduct Starter N	– _____
H. Deduct Manure N Credits[1]	– _____
I. Preplant Additional N (F–G–H)	= _____
OR	
J. Sidedress Additional N (If Additional N is applied side-dress, multiply value I by the appropriate value in Table J)	_____

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[1] Manure N Credits can be found in Chapter 9, *Soil Fertility and Nutrient Use*.

Table A. Base N Requirement

Soil Texture	**Base N Requirement** **Southwestern and Central Ontario**	**Eastern Ontario***
Clay, heavy clay	53	1
Clay loam	40	1
Loam	32	1
Loamy sand	46	19
Sandy loam	38	19
Sand	52	19
Sandy clay, sandy clay loam	43	19
Silt loam	20	1
Silty clay loam	36	1
Silty clay	49	1

* Eastern Ontario includes Frontenac, Renfrew and counties to the east of them.

Table D. Previous Crop Adjustments

Previous Crop	**Adjustment**
Grain Corn	0
Silage Corn	14
Cereals	12
Soybeans	30
Dry edible beans	30
Clover cover crop (plowed)	82
Clover cover crop (no-till)	67
Perennial Forages	
Less than one-third legume	0
One-third-to-half legume	55
Over half legume	110

Table E. Price Ratio (PR) Adjustment for Nitrogen Relative to Corn Price

Corn Price $/T	**Nitrogen Price $/kg N** **1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**
120	36	50	64	78	*	*
130	31	44	57	70	82	*
140	26	38	50	62	74	*
150	22	34	45	56	67	78
160	19	29	40	50	61	71
170	16	26	35	45	55	65
180	13	22	32	41	50	60
190	11	19	28	37	46	55
200	8	17	25	34	42	50
210	6	14	22	30	38	46
220	5	12	20	27	35	43
230	3	10	17	25	32	39

* Adjustments for these price ratios have not been assessed.

Table J. Timing Adjustment (Southwestern and Central Ontario only)

Soil Texture	**Adjustment**
Clay, clay loam, loam, silt loam, silty clay, silty clay loam	0.8
Sandy clay, sandy clay loam, sandy loam	0.9
Sand, loamy sand	1.0

Table 1–25. Phosphate and Potash Recommendations for Corn Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating[1]	Phosphate (P_2O_5)[2] Required kg/ha	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[2] Required kg/ha
0–3	HR	110	0–15	HR	170
4–5		100	16–30		160
6–7		90	31–45		140
8–9		70	46–60		110
10–12	MR	50	61–80	MR	80
13–15		20	81–100		50
16–20		20	101–120		30
21–30	LR	20	121–150	LR	0
31–60	RR	0	151–250	RR	0
61+	NR[3]	0	251+	NR[3]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR, and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] Where manure is applied, reduce fertilizer applications according to the amount and quality of manure (see Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page 164).

[3] When the response rating for a nutrient is "NR," application of this nutrient in fertilizer or manure may reduce crop yield or quality. For example, phosphate applications may induce zinc deficiency on soils low in zinc and may increase the risk of water pollution. Potash application on soils low in magnesium may induce magnesium deficiency.

Nitrogen Application

The major portion of the nitrogen should be applied in the spring, preplant, pre-emergence or side-dressed before the corn is 30 cm (12 in.) high. Fall application is not recommended because of the potential for high losses.

A portion of the nitrogen may be applied in a band at planting. Ensure that safe rates of fertilizer near the seed are not exceeded. Where it is desirable to apply high rates of nitrogen at planting, it should be placed in a separate band greater than 10 cm (4 in.) from the seed row.

Solid forms of nitrogen or urea-ammonium nitrate solutions (UAN) may be applied to the soil surface without incorporation. However, incorporate urea or UAN applied on crop residues into the soil immediately to prevent ammonia volatilization losses. Under dry conditions, the effectiveness of all forms of nitrogen may be improved by incorporation. If UAN solutions contact leaves, burning and yield reductions may occur.

Anhydrous ammonia, applied with conventional equipment, should be placed a minimum of 15 cm (6 in.) deep in the soil. For preplant applications, applicator outlets should be no more than 50 cm (20 in.) apart. For wider spacings, a 4-day waiting period before planting is recommended to avoid damage to seedlings.

When appropriate equipment is used, ammonia may be applied with a cultivator or disc, a minimum of 10 cm (4 in.) deep with the ammonia outlets spaced no more than 50 cm (20 in.) apart.

Phosphate and Potash

Adequate phosphorus and potassium are necessary for optimum corn growth and yield, although the response to these nutrients is not as evident as with nitrogen. Phosphorus deficiency does not show any obvious symptoms, although phosphorus-deficient plants will be stunted and may have a darker green or purplish colour. Purple leaves may also be an indication of cool weather stress or root injury (Plate 2 on page 279). Potassium deficiency symptoms appear on the lower leaves of the plant first, showing as yellowing and browning beginning at the tip and proceeding back along the outside margin of the leaf (Plate 3 on page 279). Both of these nutrients will exhibit "hidden hunger," where yields are reduced by a deficiency of one or both of these nutrients even though no deficiency symptoms are visible.

Phosphate and potash recommendations for corn are presented in Table 1–25, *Phosphate and Potash Recommendations for Corn Based on OMAFRA-Accredited Soil Tests*, this page.

For information on the use of this table or if an OMAFRA-accredited soil test is not available, see *Fertilizer Recommendations*, on page 158.

Where soil tests indicate that large amounts of phosphorus and potassium are required, the major portion may be broadcast and incorporated in the fall or spring. Where soil tests show a moderate or small requirement for these nutrients, apply a fertilizer containing nitrogen (preferably in the ammonium form) and phosphorus, or nitrogen, phosphorus and potassium as a starter at planting. All of the phosphorus and some of the potassium may be applied in a band 5 cm (2 in.) to the side and 5 cm (2 in.) below the seed (see Table 9-21, *Maximum Safe Rates of Nutrients*, on page 176).

Seed-Placed Fertilizer

Field trials over several years have shown that an application of 10–15 kg/ha (9–13 lb/acre) P_2O_5 directly with the seed will give greater yield increases than 20 kg/ha (18 lb/acre) P_2O_5 in a side band. At phosphorus soil tests of 13–45, this "with-seed" application is more likely to give a profitable response than a side-band application. At soil tests below 13, application of 10–15 kg P_2O_5/ha (9–13 lb P_2O_5/acre) with the seed may also be profitable but cannot replace the requirement for additional phosphorus in the side band or broadcast.

Fertilizers applied with the seed that contain nitrogen in the ammonium form must be low in salt and must not contain either urea or diammonium phosphate (see Table 9-21 on page 176). They must also be distributed uniformly to avoid toxicity to the germinating seed. Application of more than 15 kg/ha (13 lb/acre) P_2O_5 with the seed in 75-cm (30-in.) wide rows is not recommended.

Maximum Safe Rates of Fertilizer

Applying too much fertilizer to corn may result in crop injury, either from excessive salts or ammonia (Plate 8 on page 280). The more concentrated the fertilizer and the closer it is to the seed, the greater the risk of crop injury and the lower the safe rate. Maximum safe rates are given in Table 9-21 on page 176. Note that slight reductions in crop growth and yield are possible with these application rates under adverse weather conditions.

Secondary and Micronutrients

Magnesium

Magnesium is plentiful in most Ontario soils, but deficiencies can occur on acidic, sandy soils. The symptoms appear first as yellow striping of the lower leaves (Plate 4 on page 279). As the deficiency worsens, the upper leaves may become striped while the lower leaves turn reddish-purple.

Dolomitic lime is an excellent source of magnesium where limestone is required to correct soil acidity and should be used whenever the magnesium test is less than 100 ppm. For further information, see *Soil Acidity and Liming*, on page 158.

Few soils that do not need lime will require magnesium. Magnesium application is recommended only if the magnesium test is under 20 ppm. On these soils, magnesium can be supplied either by magnesium sulphate or, if potassium is also required, by sulphate of potash magnesia. Apply 30 kg/ha (27 lb/acre) of water-soluble magnesium.

Over-application of potassium can induce magnesium deficiency. For this reason, it is important to monitor soil potassium levels closely and restrict potash application rates to those recommended by the OMAFRA-accredited soil test.

Sulphur

Sulphur deficiency in corn has not been observed in Southern Ontario. Most corn-growing areas of the province receive adequate sulphur as acid precipitation. Corn grown in Northwestern Ontario may respond to the inclusion of 15 kg/ha (13 lb/acre) of sulphate sulphur with the fertilizer.

Zinc

Zinc deficiency occurs on corn in Ontario. Visible symptoms on the leaves (Plate 5 on page 279) are the best indications of deficiency, but soil tests are also useful. Zinc deficiency usually appears as a broad white band near the base of the younger leaves on a corn plant. In severe deficiencies, the entire leaf in the whorl will be white (known as "white-bud"). Response to zinc should not be expected unless deficiency symptoms are quite marked.

When zinc is required, it may be applied to the soil mixed in the fertilizer at rates supplying 4–14 kg/ha (3.5–12.5 lb/acre). The higher rate should be sufficient for up to 3 years. Not more than 4 kg/ha (3.5 lb/acre) should be banded at planting. Zinc may be applied as a foliar spray at rates supplying 60 g/100 L (0.6 lb/100 gal). A wetting agent should be added. Spray to leaf wetness.

Manganese

Manganese deficiency in corn is rare, although there have been a few occurrences reported on muck soils with high pH in Southwestern Ontario. Corn is much more tolerant of low soil manganese levels than soybeans or cereals. Manganese deficiency in corn appears as an olive-green discolouration of the leaves, occasionally with faint striping. Foliar application of manganese is the most effective way to correct a deficiency.

Table 1–26. Interpretation of Plant Analysis for Corn

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Seedling Corn (5–6 leaves)			
Phosphorus	%	0.35	0.70
Zinc	ppm	20.0	70.0
Silking (mid-third of leaf opposite ear)			
Nitrogen (N)	%	2.5	3.5
Phosphorus (P)	%	0.28	0.50
Potassium (K)	%	1.2	2.5
Calcium (Ca)	%	—	1.5
Magnesium (Mg)	%	0.10	0.60
Sulphur (S)	%	0.14	—
Boron (B)	ppm	2.0	25.0
Copper (Cu)	ppm	2.0	20.0
Manganese (Mn)	ppm	15.0	150.0
Zinc (Zn)	ppm	20.0	70.0

[1] Yield loss due to nutrients deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

Correct the deficiency as soon as detected by spraying the foliage with 2 kg/ha (1.8 lb/acre)of actual manganese/ha from manganese sulphate (8 kg/ha (7.1 lb/acre) of manganese sulphate) in 200 L of water. A "spreader-sticker" in the spray is recommended. If the deficiency is severe, a second spray may be beneficial. Prior to applying micronutrients, take care to properly clean out the spray tank of a sprayer that has been used to apply herbicides.

Other Micronutrients

Other micronutrients are not likely to be deficient in corn in Ontario. Some micronutrients, such as boron, can be toxic if applied to corn, particularly if applied in a band or in the starter/pop-up fertilizer.

Plant Analysis

The most appropriate growth stage for sampling corn for plant analysis changes for different nutrients. For most nutrients, sampling the mid-third of the ear leaf at silking is most appropriate. For phosphorus and zinc, sampling the whole plant when 5–6 leaves are visible is more appropriate. See Table 1–26, *Interpretation of Plant Analysis for Corn*, this page, for normal concentrations of nutrients.

For sampling at times other than those indicated above, take plant samples from both deficient and healthy areas of the field for comparative purposes. For plants with six leaves or less, sample the total above-ground plant. From seven leaves to silking, sample the youngest fully developed leaf. Take a soil sample from the same areas and at the same time as the plant samples. For more information, see the section *Plant Analysis*, on page 157.

Foliar Fertilization

The foliar application of nutrients to corn has not proven effective in most instances. The rates of nutrients required cannot be applied as a foliar spray without causing damage to the leaf, unless numerous small applications are made. The exception is correction of some of the micronutrient deficiencies, but even in these cases it is often more economical to apply the nutrient to the soil.

Harvesting and Storage

Corn Harvest

Physiological maturity (black layering) occurs when the grain moisture content reaches 31%–33% moisture. After this stage, there is no dry matter added to the corn kernel. Harvesting grain corn at moisture contents above 28% often results in significant damage to the grain and makes it more difficult to market commercially. High quality food grade markets may require harvest moistures to be as low as 20%–22%.

Weigh the benefits of delaying harvests to lower drying costs and improve sample quality against the increased risks that come from higher levels of stalk lodging, ear drop and wet weather. Determine the need to adjust harvesting dates forward to prevent harvest losses by scouting fields and checking for stalk quality. When stalk quality is poor, the next significant wind or rainstorm may increase harvest losses dramatically. Efficient header performance is also important when harvesting corn with poor stalk strength. Keep header speed in step with ground speed to improve stalk flow down through the stripper plates and snapping rolls. If necessary, adjust them closer together.

Damage to grain quality by the combine can result from any of the following:

- cylinder speed too high
- concave clearance too narrow
- too many concave filler bars
- concave and cylinder not parallel

When harvesting corn that has been frozen prior to maturity, experience generally indicates that running the cylinder speed as slow as possible is the key to maintaining quality.

Use these guidelines to assess combine harvest losses:

- 22 kernels per square metre (2 kernels per square foot) represents approximately 0.06 t/ha (1 bu/acre) in losses
- one average-sized ear in 1/100 acre (6.4 x 6.4 m (21 x 21 ft)) represents 0.06 t/ha (1 bu/acre) in lost yield

If combine losses exceed 0.16 t/ha (2.5 bu/acre), make adjustments.

Harvesting and Storing Corn Silage

See *Haylage and Corn Silage*, on page 73.

Corn Storage

Drying and Storing Corn

The three general types of grain dryers used on the farm are:

- in-bin
- batch
- continuous flow

No single drying system is superior to all others in every respect. Grain drier selection is dependent on desired features including drying capacity, grain quality, fuel/drying efficiency (BTUs per volume of water removed), convenience, manpower required to run the dryer, ability to dry a variety of crops, maintenance required and capital cost.

All dryers move "dry" air past the grain to evaporate moisture within the kernel and carry the water vapour away. Heat is added to this drying air to reduce its relative humidity, thereby increasing its ability to pick up moisture. Wet grain can be dried at higher temperatures, without damaging the corn, because the corn is cooled as the moisture evaporates from the kernels. As the grain dries, it will approach the temperature of the drying air. The longer grain kernels are in contact with this heated air, the drier and hotter the kernels will get.

Drying Corn With Heated and Unheated Air

Corn dries as the moisture from the inside of the kernels is evaporated from the kernel surface. Most of the moisture inside the kernel exits through the tip end of the kernels. The first few points of moisture can be easily removed using relatively little energy. Further moisture must be removed from deep within the corn kernels. As the outside layers of the kernel dry, the moisture must migrate out from the moist centre. This moisture does not move to the surface as quickly as it is being evaporated from the surface of the kernel by the drying air. This results in higher energy requirements to remove the last few percentage points of moisture.

Table 1–27. Maximum Recommended Air Temperatures for Drying Corn of Various End Uses

End Use	Maximum Drying Temperature (°C)
Seed corn	45
Starch milling	70
Industrial uses, non-ruminant feed	90
Cattle feed	120

Drying Temperatures

A range of drying temperatures can be used to dry corn but should not exceed the maximum recommended air temperatures in Table 1–27, *Maximum Recommended Air Temperatures for Drying Corn of Various End Uses*, this page. The maximum recommended drying temperature depends on several factors, including final end use of the grain, initial moisture content of the grain, type of grain and type of dryer.

Viability is destroyed when the actual grain temperature exceeds approximately 50°C. Reduction in nutritional value occurs when grain temperature reaches 90°C–100°C.

Kernel Quality

Taking corn hot out of the dryer, allowing it to steep for a time and then aerating the corn with a minimum of 6.5 L/sec/m^3 (0.5 CFM/bu) airflow will reduce stress cracking.

Stress cracking and physical kernel damage are influenced by the speed of moisture removal and maximum kernel temperature, coupled with the rate of cooling after drying.

In addition to maintaining grain quality, using this system of dry-aeration or cool-aeration can increase the throughput of the drying system. Many farmers in Ontario practice "cool-aeration," where corn is removed hot from the drier, transferred to a storage bin and cooled slowly. In this way, hot corn is continuously being added to the top of the final storage bin and slowly cooled.

Natural-Air Drying

Natural-air drying of corn is possible in most parts of Southern Ontario. This method of drying corn is well suited for livestock operations to produce high-quality corn that is free of stress cracks. Good management of a natural-air drying system is critical to success.

Minimum Requirements for Natural-Air Drying

- full aeration floor in the bin
- level grain surface across the whole bin

- minimum airflow of 26 L/sec/m^3 (2 CFM/bu), preferably more
- corn 25% moisture content or less
- clean corn with no cob pieces or fines
- accurate moisture reading of the corn in the bin
- accurate outside air temperature and relative humidity measurement
- an understanding of corn equilibrium moisture content
- coring the bin (auger out some grain) after filling. The best way is to remove a couple of loads from the bin. This establishes the flow funnel and removes the highest concentration of fines from the centre of the bin. Clean these loads before placing them back into the bin. Even if the loads are put right back in the bin without cleaning, the resistance to airflow will be less than if the bin had not been cored.
- an on/off switch for the fan

When to Run the Fan

Fan operation in a natural-air corn-drying bin is slightly different than for other air-dried crops. Once there is sufficient corn in the bin to hold the perforated floor down, the fan can be turned on. Run the fan continuously for the first 3 weeks after the bin has been filled or until the first drying front has come through the top of the bin.

The first drying front emergence will be evident when there is a noticeable drop in the moisture content of the corn at the top of the bin. Before this drying front passes through, the corn at the top of the bin will remain at harvest moisture levels and may even increase slightly compared with the corn drying further down. If the fan is shut off for an extended period of time at the start of the drying process, there is a risk that the drying front may stall and will not move upwards once the fan is turned on again. This will result in spoilage occurring above the drying front.

> Rain or shine, the fan should not be turned off until the first drying front has passed through the whole bin.

Once the first drying front passes through the top of the bin, begin to manage the fan operation, using the equilibrium moisture chart for corn (see *Equilibrium Moisture Content*, this page). Run the fan any time the outside conditions will still allow the wettest corn in the bin to dry. At times, this procedure may add some moisture to the corn at the bottom of the bin. This temporary rewetting of the bottom corn will actually dehumidify the air so it can do more drying up higher in the bin.

The corn may not reach the desired moisture content before freezing weather arrives. Trying to accomplish natural-air drying in below-freezing temperatures is very slow and inefficient. The last few points of moisture may have to be taken out in early spring. Some livestock producers never finish drying the corn any further after winter, since it processes and stores well as feed at the higher moisture levels.

Table 1–28. Equilibrium Moisture Content for Corn Exposed to Air

Temperature °C	Relative Humidity (% Wet Basis)				
	50%	60%	70%	80%	90%
0	13.7	15.1	16.6	18.4	21.3
5	13.1	14.4	15.9	17.8	20.7
10	12.5	13.8	15.4	17.3	20.2
15	11.9	13.3	14.9	16.8	19.8
20	11.5	12.8	14.4	16.4	19.4
25	11.0	12.4	14.0	16.0	19.0

Humidistats are available that will activate the fan at preset humidity levels. The operator can adjust and set the relative humidity level at which the fan is activated. Bins with stirrators will have fairly uniform moisture levels throughout the whole bin as a result of the mixing that has occurred.

Corn at moisture levels greater than 25% can also be dried in a natural-air bin. This is accomplished by only partially filling the natural-air bin, resulting in an airflow of 52–78 L/sec/m^3 (4–6 CFM/bu). Producers who need corn for feed in late September can harvest headlands and put this in the bin. The warm temperatures in late September, combined with higher CFM/bu airflow enable this corn to be dried in a couple of weeks.

Equilibrium Moisture Content

Researchers have developed equilibrium moisture content tables that predict the final moisture content of corn when exposed to air at a certain temperature and relative humidity (see Table 1–28, *Equilibrium Moisture Content for Corn Exposed to Air*, this page). For example, to determine the equilibrium moisture content of corn exposed to outside air at 10°C and 70% relative humidity, find the point at which the 10°C line and the 70% relative humidity line intersect. This point (15.4%) will be the equilibrium moisture content.

Other Crop Problems

Insects and Diseases

Figure 1–2, *Corn Scouting Calendar*, opposite page, shows insects and diseases that could be causing the symptoms in the field. Individual descriptions of insects, pests and diseases , scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, or Chapter 14, *Diseases of Field Crops*.

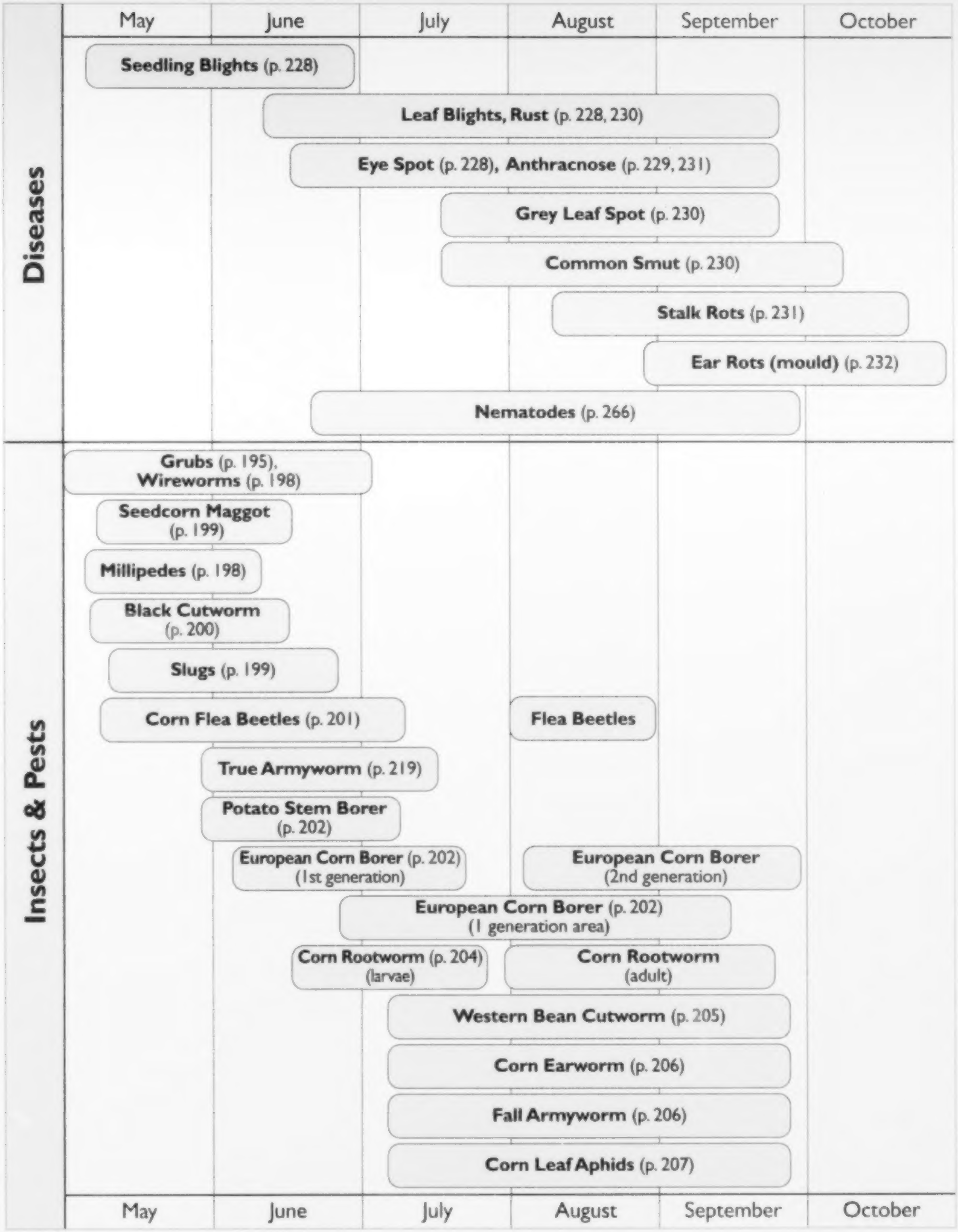


Figure 1–2. Corn Scouting Calendar

Cold

Early-Season Cold

Frost damage in May or June will generally have little impact on the crop, providing the growing point of the corn plant is still below the soil surface. This is the case until the young plant reaches roughly the sixth-leaf stage. On more advanced plants and/or where damage is more severe, split stalks to see if the growing point has been damaged. This procedure will require some time to make the correct recommendation. It probably takes 3–5 days following a frost to accurately determine the degree of damage, to verify the presence of healthy growing points (yellowish-white and firm) or to see new leaf growth.

Frozen leaf tissue bleaches to a straw colour several days after freezing. In some cases, it also develops a "knot," which may restrict expansion of the undamaged tissue lower in the whorl (Plate 9 on page 280). It often appears that clipping these knots by mowing the field aids in the plant's recovery, but this is mostly cosmetic. Tests conducted on frosted corn fields concluded that clipping appeared to help the fields "green up" but that unclipped sections of the same fields often recovered as quickly and yielded as much or more than the clipped sections.

There is very little that can be done to minimize the potential problem. Some management factors that increase the risk of frost damage to corn should temperatures fall are:

- inter-row cultivation
- side-dressing nitrogen (where soil is disturbed)
- herbicide applications
- presence of weeds
- high levels of previous crop residue

If the forecast calls for a risk of frost, consider delaying inter-row cultivation, nitrogen side-dressing or herbicide applications until warmer temperatures return. Soil disturbance at the surface introduces more air into the soil and insulates the corn plants from the heat of the soil mass, thus increasing the risk of frost damage. Similarly, crop residues and weeds act as a barrier for heat transfer from the soil to the corn plant. Dry soils are more prone to frost damage because they have a lower capacity to store heat during the day and thus less heat to transfer and protect the corn plant overnight.

Late-Season Cold

Cold temperatures during the grain-filling period in August and September may cause yield and quality losses. The extent of these losses depends on the developmental stage of the corn and the temperatures recorded.

As temperatures drop to 0°C, frost damage first occurs to the leaves of the corn plants. This damage will eliminate any further photosynthesis, reduce grain filling and often have a negative effect on stalk strength. However, as long as air temperatures do not fall below –2°C, stalk tissues will remain viable and stalk constituents will be mobilized to fill the ear as much as possible. On the other hand, if temperatures fall below –2°C, both leaves and stalks may be damaged and no further photosynthesis or remobilization can occur. This will terminate grain filling, and kernel black layer will develop. Table 1–29, *Estimated Risks to Grain Corn Yield and Quality From Late-Season Frost Damage*, this page, outlines the potential risks to yield and quality for grain corn experiencing different levels of frost damage.

Table 1–29. Estimated Risks to Grain Corn Yield and Quality From Late-Season Frost Damage

Crop Growth Stage	Frost Damage	Estimated Grain Yield Loss	Grain Quality Concerns
Mid-dough	Complete plant	40%	Severe
Mid-dough	Leaves only	25%	Severe
Early dent	Complete plant	25%	Moderate
Early dent	Leaves only	15%	Moderate
Half milk line	Complete plant	10%	Minor
Half milk line	Leaves only	0%–5%	None

Note: This table is meant as a guide; differences among hybrids, overall plant vigour at time of frost and subsequent temperatures will all affect final grain yield and quality.

Generally the early dent stage is the cut-off point where corn can withstand frost damage to the leaves and still produce a reasonable grain yield. This stage is characterized by having kernels showing small indentations in the crown of the kernel, at least in the lower half of the cob.

The other question regarding cold nights revolves around the corn crop's ability to continue grain filling after experiencing several cold nights without frost damage. Dr. Thys Tollenaar of the University of Guelph has conducted research that measured 50% reductions in photosynthesis and rate of grain filling due to cold nights of 2°C. However, when these plants were restored to higher temperature conditions, they resumed plant activities at rates similar to those plants that had never experienced the low temperatures. If cornfields can escape any serious frost damage during cold nights, grain filling should carry on once normal temperatures return.

In some situations, frost damage will preclude harvesting the crop as grain and will force the grower to consider harvesting it as silage. There are important issues surrounding the management of the silage crop as well. Following a frost, silage corn frozen before reaching the

Table 1–30. Estimated Percentage Corn Grain Yield Loss Due to Defoliation at Various Growth Stages

	% Leaf Defoliation																		
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
Growth Stage[1]	**% Yield Loss**																		
7 leaf	0	0	0	0	0	0	1	1	2	3	4	4	5	5	6	7	8	9	9
9 leaf	0	0	0	1	1	2	2	3	4	5	6	6	7	7	9	10	11	12	13
11 leaf	0	0	1	1	2	3	5	6	7	8	9	10	11	12	14	16	18	20	22
13 leaf	0	1	1	2	3	4	6	8	10	11	13	15	17	19	22	25	28	31	34
15 leaf	1	1	2	3	5	7	9	12	15	17	20	23	26	30	34	38	42	46	51
17 leaf	2	3	4	5	7	9	13	17	21	24	28	32	37	43	48	53	59	65	72
18 leaf	2	3	5	7	9	11	15	19	24	28	33	38	44	50	56	62	69	76	84
19–21 leaf	3	4	6	8	11	14	18	22	27	32	38	43	51	57	64	71	79	87	96
Tassel	3	5	7	9	13	17	21	26	31	36	42	48	55	62	68	75	83	91	100
Silked	3	5	7	9	12	16	20	24	29	34	39	45	51	58	65	72	80	88	97
Silks brown	2	4	6	8	11	15	18	22	27	31	36	41	47	54	60	66	74	81	90
Pre-blister	2	3	5	7	10	13	16	20	24	28	32	37	43	49	54	60	66	73	81
Blister	2	3	5	7	10	13	16	19	22	26	30	34	39	45	50	55	60	66	73
Early milk	2	3	4	6	8	11	14	17	20	24	28	32	36	41	45	50	55	60	66
Milk	1	2	3	5	7	9	12	15	18	21	24	28	32	37	41	45	49	54	59
Late milk	1	2	3	4	6	8	10	12	15	18	21	24	28	32	35	38	42	46	50
Soft dough	1	1	2	2	4	6	8	10	12	14	17	20	23	26	29	32	35	38	41
Early dent	0	0	1	1	2	3	5	7	9	11	13	15	18	21	23	25	27	29	32
Late dent	0	0	0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mature	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Adapted from the *National Crop Insurance Services Corn Loss Instruction* (Rev. 1994). Used with permission.

[1] As determined by counting leaves using the leaf-over method (i.e., those with 40%–50% of leaf exposed from whorl and whose tip points below the horizontal).

half milk line on the kernel may be too high in moisture to properly ensile. Ideally, in cases of frost, delay corn harvest until the entire plant reaches the desired moisture content for ensiling.

Heat

Heat stress is different from drought stress. Corn can usually tolerate temperatures as high as 38°C before injury occurs, as long as drought conditions are not present as well. Temperature and drought sensitivity varies by hybrid. Drought-tolerant hybrids may result in yield drag. They are not likely good choices for a normal growing season.

Hail

Cornfields damaged by hail may experience a reduction in leaf surface area, bruising of the stalk and ear and, in serious incidences, stalk breakage (Plate 10 on page 280). Yield loss due to hail is dependent on the stage of the crop at the time of the hail event and the level of defoliation. Yield loss is greatest when the corn is defoliated during tasselling. Younger plants may experience a delay in growth and development due to hail, but yield loss is usually minimal. Defoliation of plants near maturity tends to cause little yield loss. See Table 1–30, *Estimated Percentage Corn Grain Yield Loss Due to Defoliation at Various Growth Stages*, this page, when making yield loss estimates due to hail damage. Hail damage may also provide an entry point for diseases such as smut.

Flooding

Flooding stresses the plant by cutting off the supply of oxygen to the root system. Younger corn plants die if submerged in water for more than 5 days, especially in warmer weather conditions. If air temperatures are high, death may occur in only a few days, as plant processes are sped up and the need for a supply of oxygen to the roots is high. In cooler weather, submerged plants may live for up to a week. After the 8-leaf stage of corn, plants can tolerate being submerged in water for more than 8 days but may be more susceptible to disease and may experience limited root development while under water.

Yield loss due to flooding is most substantial for plants submerged immediately before and during tasselling and silking. Plants in the later vegetative growth stages (10–16 leaves) and/or during the grain filling period, suffer little yield loss to flooding.

Drought

The corn crop requires approximately 50 cm of water to produce high yields. This can be supplied over the growing season from a combination of stored water in the soil, rainfall or irrigation.

Lack of water causes the leaves to wilt and turn a greyish colour (Plate 6 on page 279). Corn is most susceptible to dry conditions during the tasselling-to-silking stage and may experience yield loss if under stress at this time. During the later vegetative stages of growth (V8–V14), the plant may benefit from dry conditions, as it forces the more rapid downward growth of the roots. Drought conditions during silking can reduce pollination and a lack of silk emergence, while drought after silking may cause a reduction in grain fill.

Bird Damage

Birds can damage emerging seedlings. However, the more serious bird damage occurs to grain in August and September (Plate 11 on page 280). Birds eat the kernels off the cob, causing direct yield loss, and kernel damage may result in mould growth. Bird damage can be easily confused with seedling damage caused by black cutworms or ear damage caused by grasshoppers. Noisemakers, such as Av-alarms, propane cannons, exploding shotgun shells, the Phoenix Wailer and recordings of bird distress calls may be successful deterrents if more than one technique is used and their pattern is changed frequently. If crop damage due to birds or wildlife is substantial, contact your local Ministry of Natural Resources office for control options.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide.*

2. Soybeans

Over 809,000 ha (2 million acres) of soybeans are grown annually in Ontario. The development of earlier maturity varieties, a wider selection of herbicides, adaptability to no-till production and the relative low cost of production have contributed to the widespread adoption of soybeans in the province.

Glyphosphate-tolerant varieties make up about two-thirds of the crop, while about one-third is non-GMO (genetically modified organisms). The demand for specialty soybeans with identity preservation (e.g., food grade, non-GMO, organic, etc.) has created marketing opportunities for Ontario beyond the traditional end use of soybeans for oil production and livestock feed.

Tillage Options

The wide adaptation of soybeans to various tillage systems, particularly no-till, has contributed to the expansion in soybean acreage. Approximately two-thirds of the soybean crop is grown under no-till systems or with reduced tillage systems. Field experience and research trials have shown similar yields between tillage systems. Management of the tillage system used is as important as the actual system selected.

Table 2–1. Soybean Yield Response Under Various Tillage Systems

	Row Width cm (in.)				
	Single 76 cm (30 in.)	**Twin 76 cm (30 in.)**	**56 cm (22.5 in.)**	**38 cm (15 in.)**	**19 cm (7.5 in.)**
Tillage[1]	**Soybean Yields t/ha (bu/acre)**				
No-till	2.72 (40.4)	3.04 (45.3)	2.93 (43.6)	3.06 (45.5)	3.06 (45.5)
Fall moldboard	2.94 (43.8)	3.02 (44.9)	2.93 (43.6)	3.12 (46.4)	3.21 (47.7)
Fall zone-till	2.78 (41.3)	2.93 (43.6)	–	–	–
Spring zone-till	2.71 (40.3)	3.02 (45.0)	–	–	–

Least Significant Difference[2] (P = 0.05) = 2.42 bu

[1] Average of nine sites per year. University of Guelph (1998–2000). Trials were conducted on clay loam, silty-clay loam, silt loam and Guelph loam soil types. Spring zone-tillage conducted approximately 1 day prior to planting.

[2] Where the difference between two treatments exceeds 2.4 bu/acre, there is a less than 1-in-20 chance that it is due to random variation.

No-Till and Minimum Tillage

Ontario tillage research found that no-till soybean yields were similar to the fall moldboard plow in row widths of 56 cm (22.5 in.) or less and in twin rows (see Table 2–1, *Soybean Yield Response Under Various Tillage Systems*, this page). Although the yields were comparable between the two tillage systems, no-till input costs were often lower and profit higher. Where single 76-cm (30-in.) rows were used, moldboard plowing produced the highest yields. When soybeans were planted in twin rows, soybean yields improved over 76-cm (30-in.) rows for all tillage systems. In this study, zone tillage showed no significant yield improvement over no-till. Some Ontario research trials have shown a small yield advantage (0.13 t/ha, 2 bu/acre) to conventional tillage over no-till. In general, there is a greater positive response to tillage in fields with a poor crop rotation compared to a rotation with fewer soybeans.

The keys to successful no-till production are to minimize compaction, manage residue and plant only when soil conditions are fit. The adoption of no-till on heavy textured soil types (clay, silty clay loam or silty clay) can be more challenging than on lighter soils. In some years, growers have experienced reduced no-till soybean yields on these soil types compared to conventional tillage. However, as demonstrated in Table 2–2, *Soybean Yields for Ridgetown College, University of Guelph, 1992–2000*, this page, research on Brookston clay soils resulted in equal yields for no-till and fall moldboard tillage over the long term.

Planting in no-till fields is often done later than in conventionally tilled fields due to wetter and cooler soil conditions. Some producers mitigate this problem with springtime minimal tillage (pre-tillage). Tillage with

Table 2–2. Soybean Yields for Ridgetown College, University of Guelph, 1992–2000

	Average Yield[1] (excluding 1996)	
Tillage Treatment	**t/ha**	**bu/acre**
Fall moldboard plow	3.21 a	47.7 a
No-till	3.21 b	47.8 a
Fall chisel plow	3.05 b	45.4 b
Ridge tillage	2.96 b	44.1 b
Zone tillage	3.06 b	45.5 b

Least Significant Difference (P = 0.05) = 2.2 bu

[1] Values followed by the same letter are not significantly different at the 5% level.

Table 2–3. Soybean Yield Response to Spring Minimal Tillage (2003–05)

Treatment[1]	Average Yield[2] (excluding 1996) t/ha	bu/acre
No-till drill	3.03 c	45.1 c
No-till drill with coulters (3.8-cm depth)	3.05 c	45.4 c
No-till drill with coulters (9-cm depth)	3.09 b	46.0 b
Pre-tillage (operated 1–3 days prior to seeding at 9 cm)	3.15 a	46.9 a
Least Significant Difference (P = 0.05) = 0.4 bu		
Source: Bohner, OMAFRA.		

[1] Values based on 40 trials seeded with a JD 1560 no-till drill. Coulters run at seeding time in the row (2-cm or 0.75-in. coulters). Pre-tillage coulter unit operated 1–3 days before seeding at a depth of 9 cm (4.5 cm or 1.75 in. coulters). No coulters run on JD drill for pre-tillage treatment.

[2] Values followed by the same letter are not significantly different.

a one-pass coulter unit has shown a small yield benefit over straight no-till. Coulters run at the time of planting have also shown a marginal benefit if run at a depth of 9 cm (3.5 in.). Coulters operated at a depth of 3.8 cm (1.5 in.) showed no yield gain in the research summarized in Table 2–3, *Soybean Yield Response to Spring Minimal Tillage (2003–05)*, this page.

When soybeans follow a cereal crop, pay special attention to the management of cereal residue — beginning at harvest — to avoid problems with soybean establishment. The best action is to remove the straw and spread the chaff evenly. In research trials done at the University of Guelph, removal of the wheat straw improved seedbed conditions, stand establishment, growth and yield of no-till soybeans. The results are shown in Table 2–4, *Effect of Tillage and Wheat Residue Management on Soybean Yields (1994–96)*, this page. Cereal residue can form a mat that slows soil warming and drying in the spring. This can delay soybean planting, reduce soybean emergence and early growth, and lead to increased damage from slugs. Minimum tillage in the fall or spring without the need for secondary tillage improves seedbed conditions and creates looser, finer soil to improve early soybean growth, while maintaining adequate residue to reduce erosion.

It is best to avoid tillage along highly erodable knolls and slopes. In these situations, it may be sensible to use tillage only where the soil routinely remains cooler or wetter in the spring.

Table 2–4. Effect of Tillage and Wheat Residue Management on Soybean Yields (1994–96)

Tillage (and Straw Management)	Soybean Yield t/ha	bu/acre
Fall moldboard/straw baled	3.29	48.9
Fall chisel/straw baled	3.30	49.1
Fall disk/straw baled	3.21	47.8
Fall zone-till/straw baled	3.19	47.5
No-till/all straw and stubble remain	2.27	33.8
No-till/straw baled but stubble remains	3.00	44.7
No-till/straw baled and stubble removed	3.28	48.8
Based on research at Centralia & Wyoming.		
Source: T. Vyn, G. Opuku and C. Swanton, University of Guelph.		

Note: Stubble heights were approximately 20–30 cm (10–12 in.) except for plots where stubble was cut and removed.

Soil types:
Centralia: loam, clay loam.
Wyoming: silty clay, silty clay–loam.
Soybeans were seeded with a JD 700 conservation planter equipped with a single 1.25-in. coulter. The no-till planter was equipped with tine row cleaners.

Crop Rotation Considerations

Soybeans are very responsive to crop rotation. Table 2–5, *Soybean Yield Response Under Various Crop Rotations (1997–2000)*, this page, summarizes the results of rotation studies conducted at Ridgetown College, University of Guelph. A rotation of soybeans, winter wheat and corn provided the greatest yield response. The continuous soybean rotation had the lowest yield. A short rotation leads to a build-up of disease and other long-term problems. Soybean cyst nematode (SCN) populations can increase rapidly, further reducing yields (see *Soybean Cyst Nematode*, on page 235). Maintaining a 3–4-year rotation with other non-host crops will also reduce the incidence of white mould. In fields with a history of phytophthora root rot, a short rotation contributes to an increase in the severity and number of races of the disease. The repeated use of Group 2 Herbicides–ALS inhibitors will encourage the spread of Group 2–resistant weeds.

Table 2–5. Soybean Yield Response Under Various Crop Rotations (1997–2000)

Crop Rotation	Soybean Yield t/ha	bu/acre
Continuous soybeans	2.89	43
Corn, soybeans	3.09	46
Winter wheat, soybeans	3.23	48
Winter wheat, corn, soybeans	3.23	48
Ridgetown College, University of Guelph, 1997–2000.		

Table 2–6. Soybean Maturity Dates for 2,950-, 3,050- and 3,150-Heat Unit Varieties (1990–99)

		Soybean Maturity Dates[1]		
Year	**Planting Date**	**2950 Heat Unit Variety**	**3050 Heat Unit Variety**	**3150 Heat Unit Variety**
1990	May 28	Sept. 20	Sept. 25	Sept. 30
1991	May 11	Sept. 8	Sept. 13	Sept. 20
1992	May 15	Sept. 25	Sept. 27	Oct. 2
1993	May 20	Sept. 21	Sept. 26	Oct. 1
1994	May 27	Sept. 14	Sept. 16	Sept. 21
1995	May 23	Sept. 16	Sept. 18	Sept. 21
1997	May 23	Sept. 17	Sept. 21	Sept. 27
1998	May 21	Sept. 14	Sept. 17	Sept. 23
1999	May 12	Sept. 10	Sept. 13	Sept. 19

Source: Ablett, Ridgetown College, University of Guelph.

[1] These dates are for physiological maturity. Combining would be 3–10 days after these dates.

Winter Wheat Following Soybeans

If winter wheat is to be grown following soybeans:

- Select a variety that requires about 100–200 heat units less than the number available in your area. Research from Ridgetown College, University of Guelph (1990–99), indicated that a variety requiring 100 CHUs less than a full-season variety advanced the maturity by an average of 5 days (range: 3–7 days). Going a further 100 CHUs less advanced the maturity 9 days compared to full-season varieties (see Table 2–6, *Soybean Maturity Dates for 2,950-, 3,050- and 3,150-Heat Unit Varieties (1990–99)*, this page).
- Plant the soybean crop early, as late planting will delay wheat planting.
- The wheat planting date can be calculated using the soybean planting date and the days to maturity of the soybean variety.
- Select a full-season soybean variety if broadcasting the winter wheat into a standing crop.
- Refer to the winter wheat planting dates in *Planting Dates*, on page 92.

For more information on soybean crop rotations and precautions under different tillage systems, see *Crop Rotation*, on page 147.

Variety Selection

There are over 200 soybean varieties, and their turnover in the marketplace is relatively quick. Aside from maturity and yield, base variety selection on resistance or tolerance to disease, aphids, standability and soybean cyst nematode resistance.

Maturity and CHUs

Soybean development is affected by heat unit accumulation, day-length and hours of sunshine. Disease, moisture stress and other stresses can lengthen or shorten the actual days to maturity, depending on when the stress occurs.

Select a variety that corresponds to the heat unit rating for the area. Figure 1–1, *Crop Heat Units (CHU-M1) Available for Corn Production*, on page 9, shows approximate CHUs for Ontario. Selecting full-season varieties will make maximum use of the growing season and offer the opportunity to maximize yield. When growing specialty soybeans, such as the white hilum types, selecting shorter-season varieties will help ensure quality at harvest.

Hilum Colour

The hilum is the point at which the soybean seed attaches to the pod. Varieties differ in hilum colour and can be yellow (Y), imperfect yellow (IY), grey (GR), buff (BF), brown (BR), black (BL) or imperfect black (IBL). Yellow hilum soybeans are generally the preferred type for the export market. Hilum discolouration may occur on the imperfect yellow (IY) varieties. Affected beans may not be acceptable for export markets.

Choosing Superior Varieties

In addition to maturity rating, other important factors for choosing varieties are:

- yield potential
- standability
- insect and disease resistance

In selecting superior varieties, three main sources of information exist:

- performance trial data
- on-farm strip trial data
- company information on characteristics of a variety

The Ontario Oil and Protein Seed Crop Committee conduct performance trials each year at various locations across the province. Results are published each fall in the Ontario Soybean Variety Trials brochure. This brochure is available on the Internet at www.gosoy.ca. These trials are valuable for comparing the yield potential of varieties as well as providing ratings for maturity, plant height and lodging. In Southwestern Ontario, at locations with clay soil types, varieties are evaluated for resistance to phytophthora root rot. Varieties with resistance to phytophthora root rot are recommended on heavier soils. In fields with soybean cyst nematodes (SCN), include varieties with SCN resistance regularly in the rotation (see *Soybean Cyst Nematode*, on page 235).

Seed companies will provide detailed information on growth characteristics of varieties to aid in selection. When evaluating variety performance, take into account that variety trials conducted under conventional tillage have proven to be a reliable indicator of a variety's performance under no-till conditions.

Plant fields on medium-to-light-textured soils and fields that have regular manure application or high residual nitrogen levels to a variety with reduced lodging potential. If the soybeans are intended for on-farm livestock feed, choose a variety with a high protein index.

Individual varieties may perform differently depending on growing conditions. Grow more than one variety to reduce the risk of crop failure. Plant the majority of the acreage to proven varieties while testing new varieties on a smaller scale.

Identity-Preserved (IP) Varieties

Identity preservation is the segregation of a variety from planting through to delivery to an end user. It is not a new concept but has existed in a number of markets, including seed production and the production of food-grade soybeans. The introduction of GMO crop varieties has resulted in consumer demand for identity-preserved, non-GMO soybeans. The market offers various levels of premiums and contracts to the grower.

The premiums offered for producing IP varieties must be weighed against their increased costs, time and management. Limit the acreage planted to a size that can be harvested in a timely fashion. Performance information for some specialty-trait varieties may not be available. Data for these varieties may only be available from the company selling the seed and/or agreeing to take delivery of the crop after harvest. The agronomic qualities of an IP variety, such as yield, disease resistance and maturity should be evaluated to determine whether or not the premium offered upon sale is adequate. Performance trials of a number of food-grade soybeans are conducted by the Ontario Oil and Protein Seed Crop Committee. This information is available on the Ontario Oil and Protein Seed Crop Committee website at www.gosoy.ca. For crop insurance purposes, Agricorp provides a yield adjustment factor for a number of specialty soybeans.

Biotechnology

Varieties carrying special traits, such as resistance to certain herbicides, are available in Ontario. These may have value for growers trying to address specific weed problems. They can also be useful in certain tillage systems. These varieties may not be accepted in all soybean markets.

Planting and Crop Development

Seed Quality

It is important to know the quality of the seed being planted. Certified seed must meet purity and germination standards. The quality of common seed is not known unless the germination is tested at an accredited seed lab prior to planting (see Appendix F, *Ontario Laboratories Offering Custom Seed Germination Testing*, on page 263).

Viability and Deterioration

Germination is the major quality consideration used in grading seedlots. It is the ability of a seedlot to produce normal seedlings under favourable conditions of 95%–100% humidity and 25°C. Stress conditions in the field following planting often reduce field emergence compared to that in the lab.

A better measure of the ability of seed to emerge rapidly and uniformly under a wide range of conditions is the vigour rating of the seed, called the vigour test, or more appropriately referred to as a stress test. Certified seed standards require that seed be tested for germination. In addition to germination, many seed distributors routinely test and report seed vigour.

Figure 2–1, *The Relationship Between Seed Vigour, Viability and Deterioration*, opposite page, illustrates the relationship between germination and vigour. As seed deterioration increases, germination drops slowly, whereas vigour drops very rapidly.

With Lot A, deterioration is minimal and germination and vigour are similar. On the other hand, Lot B has excellent germination but low vigour.

A number of factors can contribute to loss of seed vigour, including genetics, disease, mechanical seed damage, and deterioration in storage and weather conditions prior to harvest. The most important factor affecting vigour appears to be environmental. Time-of-harvest studies conducted by the University of Guelph suggest that vigour is lost if there is a delay between physiological maturity and harvest. Timely harvest is important if soybeans are being grown for seed.

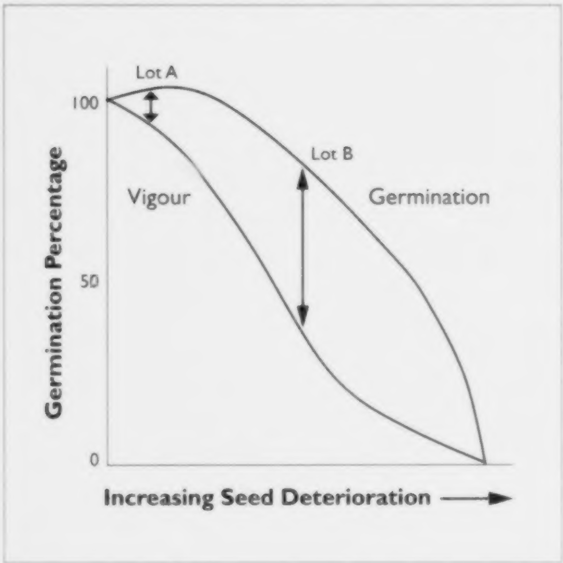


Figure 2–1. The Relationship Between Seed Vigour, Viability and Deterioration
Source: Delouche and Caldwell, 1960.

Inoculation

Biological N fixation converts gaseous nitrogen in the air (N_2) to a form of nitrogen the plant can use, namely ammonium (NH_4^+). In legumes, symbiotic nitrogen fixation occurs when rhizobia bacteria invade the root hair and form a nodule. The process of adding soybean rhizobia (*Bradyrhizobium japonicum*) to the soil is called "inoculation." The rhizobia receive a protected growing environment, carbohydrates, and minerals from the plant and in turn provide the plant with nitrogen. A 3.4 t/ha (50 bu/acre) crop of soybeans will remove 210 lb/acre of nitrogen. Some of this nitrogen comes from residual nitrogen in the soil, but between 40%–75% will come from the nodules depending on how much soil N is available.

Inoculants can be applied "on farm" at planting time or as "pre-inoculants." Pre-inoculants are formulated to allow the bacteria to survive on the seed, making it possible to inoculate the seed well before planting. These products are usually applied by a commercial seed treater and are compatible with many fungicide and insecticide seed treatments. In trials conducted by the University of Guelph, pre-inoculants show similar efficacy to inoculants applied at planting time.

The majority of products now available use a sterile peat-based carrier or a liquid formulation. Sterile-carrier inoculants use a powdered peat base that is sterilized prior to the addition of the inoculant strain. These inoculants carry much higher numbers of rhizobia than the older, non-sterile powdered peat. Non-sterile powdered peat often contains microbial contaminants, which may compete with the rhizobia.

When soybeans are grown on land for the first time, inoculation with soybean rhizobia is essential for high yields. The use of two different products or at least two different lots of the same product can improve the chances of good inoculation.

Good seed coverage is required for maximum efficacy of any inoculant. When applying "on farm," apply inoculants at the base of a brush auger when loading the planter. Kits that hang on the side of a truck, tote or gravity wagon are available from dealers. Occasionally, some growers have experienced bridging in the planter or build-up in augers from over-application of liquid seed treatments or inoculants. Simultaneous application of a low rate of peat is one option to reduce bridging.

Some seed treatments and liquid fertilizers can negatively impact inoculant performance. When using an inoculant, check the label to confirm how long the inoculant will be viable on the seed if applied with a seed treatment or mixed with a liquid fertilizer.

Inoculant is not essential where a well-nodulated, dark-green soybean crop has been grown in the past. Exceptions are acid soils (pH below 6.0), sandy soils and fields with poor drainage that have been flooded for an extended period of time. Under these conditions, inoculation is recommended for each soybean crop. A grower who is not certain that previous soybean crops were well nodulated should inoculate to avoid the possibility of poor nodulation. Ontario trials indicate a 0.1 t/ha (1.5 bu/acre) yield increase by inoculating soybeans planted into fields that have previously grown well-nodulated soybeans. Even in the absence of a soybean crop, soybean rhizobia will survive in most soils for 7–10 years and in some fields for over 50 years.

Studies have shown little success in attempting to replace existing strains of rhizobia in the soil with newer, more-effective strains. Once a strain of rhizobia has become established in the soil, it will out-compete any new strain that is introduced on the seed.

Manure or commercial nitrogen fertilizer applied to soybean fields supplies a readily available supply of nitrogen, which soybeans will use prior to that provided by the rhizobia. In these fields, nodulation may be delayed, but yields are not generally reduced. On first-time soybean ground where manure or commercial N is applied, nodulation may not occur, and unless soil nitrogen is abundant, nitrogen deficiency may be observed late in the season.

Table 2–7. Effect of Planting Date on Yield and Plant Height

Planting Date	Yield t/ha (bu/acre)	Percent of Full Yield (%)	Plant Height cm
May 10	3.23 (48)	100	104
May 24	2.96 (44)	92	93
June 7	2.75 (41)	85	89

Source: Bohner, OMAFRA, 2004–06.

Soybean roots normally become infected with *Bradyrhizobium japonicum* shortly after emergence. Nodulation of soybeans may be observed 2–3 weeks after planting. Checking fields at this point will allow time for nitrogen application, should an inoculant failure occur. In first-time fields, nodules will be located on the taproot. In previous soybean fields, nodules will also be found along lateral roots.

> Seven to 14 nodules per plant indicate adequate nodulation at first flower.

Soybeans often go through a period when leaves are light green or even pale yellow. This is the period just before the nodules start to supply adequate nitrogen to the leaves and is an important phase in the development of a healthy crop. Once the nodules have established and start providing nitrogen, the leaves will turn a dark-green colour. If proper nodulation, sufficient nutrients and moisture are present, soybeans will remain yellow for only 7–10 days.

Planting Date

Planting date is an important management tool to maximize yield potential. The highest yields of soybeans are obtained from early plantings, generally the first 10 days of May. Later plantings are likely to incur significant reductions in yield as shown in Table 2–7, *Effect of Planting Date on Yield and Plant Height*, this page.

> Soybeans are more sensitive to soil temperature than corn. However, if soil temperature and moisture conditions are suitable for planting corn, they are generally also suitable for soybeans.

A hard spring frost can kill early-planted soybeans, since the growing point of the emerged seedling is above the soil surface. However, soybean plants can withstand temperatures as low as –2.8°C for a short period of time, while corn experiences tissue damage at –2°C.

Table 2–8. Row Spacing vs. Days to Full Canopy (May Planting)

	Days to Full Canopy	
Row Spacing	Planting Before May 15	Planting After May 15
18 cm (7 in.)	30	25
38 cm (15 in.)	45	40
51 cm (20 in.)	55	50
76 cm (30 in.)	70	65

Delayed Planting

When planting is delayed, fewer days are required for the plant to reach maturity. A one-month delay in planting results in a 9-day delay at maturity. Delayed planting can reduce the vegetative growth period. This results in shorter plants with lower pods. Late planting also reduces the number of pods per plant because of the shorter flowering period. Planting date also has some effect on the duration of the pod-filling period.

> A 3-day delay in planting date generally results in a 1-day delay in maturity.

When planting is delayed beyond June 15, reduce the estimate of heat units available for crop growth by 100–200 CHUs. Planting after July 1 has largely been unsuccessful in Ontario. If planting must be delayed past July 1, select a full-season, light-hilum variety. An early frost may cause dark hilums to "bleed" into the soybean. Planting a short-day variety late in the season will result in extremely short plants with few pods.

Improve vegetative growth of late plantings by selecting taller varieties and planting in narrow rows. Using wide rows when planting late will lead to reduced yield potential. Increase seeding rates by 10%. This will increase the height of the lowest pods as well as the number of pods per acre.

Double Cropping Soybeans

Occasionally, a small number of soybean growers in the southernmost regions of Ontario have attempted to grow soybeans immediately following the harvest of their winter cereal or pea crop. Unfortunately, double cropping of soybeans in Ontario is often unsuccessful. Do not take out a good red clover stand to double crop. The benefits from the clover stand will outweigh the risk involved in a double crop venture. Do not attempt double cropping if soybean cyst nematode is a problem in the field. The soybean crop will reduce the benefits of the non-host (winter cereal) crop and increase cyst populations.

Table 2–9. Effect of Row Width on Yield

Soybean Row Width	Yield[1]
18 cm (7 in.)	3.3 t/ha (49 bu/acre)
36 cm (14 in.)	3.2 t/ha (47 bu/acre)
53 cm (21 in.)	3.0 t/ha (45 bu/acre)
71 cm (28 in.)	2.7 t/ha (40 bu/acre)

[1] Values are based on research on clay loam soils in the 3,250-CHU area. Greater response would be anticipated in shorter season regions. The response to row-width reductions is reduced under stressful growing conditions.

The following management tips will increase the chances of a successful double crop:

- At harvest, leave approximately 20 cm (8 in.) of stubble to promote soybean stem elongation and higher pod set.
- Plant immediately after a timely cereal or pea harvest.
- Plant 1 cm (½ in.) into moisture, but do not plant deeper than 7.5 cm (3 in.).
- Select tall, clear-hilum, full-season varieties if possible.
- Plant in narrow rows using high seeding rates.

Row Width

Soybeans grow well under a wide range of row widths in the long-season regions of Ontario. The choice of row width depends on factors such as tillage system, equipment suitability, weed problems, soil conditions, white mould pressure and planting date. Most soybeans grown in Ontario are solid seeded (19 cm or 7.5 in. spacing) or intermediate row widths (38–56 cm or 15–22 in.).

Wide rows allow for inter-row cultivation and are less affected by soil crusting. Narrow rows allow the crop canopy to fill in more quickly, providing maximum light interception Table 2–8, *Row Spacing vs. Days to Full Canopy (May Planting)*, opposite page, shows relative time differences to canopy cover. Quick canopy development also contributes to weed suppression.

On heavier soil types such as clay, wider row widths increase the number of seeds per foot of row, which can aid in emergence. On clay soils prone to crusting, a minimum row width of 38 cm (15 in.) has shown better emergence than solid seeded beans. Improved air movement in wider rows will also help reduce the severity of white mould.

The increase in yield potential from growing soybeans in narrow rows is greatest in the short-season areas. The yield advantage decreases towards Southwestern Ontario. Row widths of 18 cm (7 in.) are recommended in short-season areas (less than 2,800 CHUs).

Table 2–10. Solid Seeded vs. Planter Unit Yields

Seeding Rate Seeds/ha (seeds/acre)	19-cm (7.5-in.) Drill t/ha (bu/acre)[1]	38-cm (15-in.) Planter t/ha (bu/acre)
370 500 (150 000)	2.92 (43.4) b	3.03 (45.0) ab
494 000 (200 000)	3.11 (46.2) a	3.12 (46.4) a

Least Significant Difference (P = 0.05) = 2.2 bu

Source: Bohner, OMAFRA.

[1] Values followed by the same letter are not significantly different.

Grow fields prone to white mould in row widths of 38 cm (15 in.) or greater, even in short-season areas. In Southwestern Ontario, there may still be some yield advantage in reducing row widths to less than 53 cm (21 in.), as noted in Table 2–9, *Effect of Row Width on Yield*, this page, although this effect is less consistent than it is further north. Row widths of 38 cm (15 in.) have gained popularity because they allow a reduction in seeding rates compared to 19-cm (7.5-in.) rows but still provide excellent yield potential.

Table 2–10, *Solid Seeded vs. Planter Unit Yields*, this page, shows the yield impact of drilled, solid-seeded stands versus wider rows using planter units. The negative yield impact associated with slightly wider rows is offset by the more accurate seed placement when using a 38-cm (15-in.) planter compared to a drill. When using very low seeding rates, the planter will outperform the drill.

Seeding Rates

Soybeans will yield well over a wide range of seeding rates. Plants will compensate considerably for differences in stands without impacting yield. Too high a seeding rate adds unnecessary seed costs and may increase lodging and disease. Soybeans should be planted based on seeds/ha (seeds/acre) not simply by the kg/ha or lb/acre. For most soil types, there is no significant yield advantage to seeding rates over 494,000 seeds/ha (200,000 seeds/acre) as is shown in Figure 2–2, *Soybean Yield Response to Seeding Rates*, next page. Higher seeding rates (10%) are required for maximum yield potential on heavy clay soils or when using poor quality seed.

Table 2–11. Recommended Soybean Seeding Rates

Seeds/ Kilogram	Seeds/ Pound	Row Width cm (in.)			
		19 (7.5)	38 (15)	56 (22)	76 (30)
		Seeds/hectare (seeds/acre)			
		480,000 (194,000)	437,000 (177,000)	425,000 (172,000)	400,000 (162,000)
		Number of Seeds/m of row (per ft of row)			
		9 (2.8)	17 (5.1)	24 (7.2)	30 (9.3)
		Seeding Rate kg/ha (lb/acre)[1]			
4,400	2,000	109 (97)	99 (89)	98 (86)	91 (81)
4,900	2,200	98 (88)	89 (80)	88 (79)	82 (74)
5,300	2,400	91 (81)	82 (74)	82 (72)	76 (68)
5,700	2,600	84 (75)	77 (68)	76 (66)	70 (63)
6,200	2,800	77 (69)	70 (63)	70 (62)	65 (58)
6,600	3,000	73 (65)	66 (59)	65 (58)	61 (54)
7,100	3,200	68 (61)	62 (55)	61 (54)	57 (51)
7,500	3,400	64 (57)	58 (52)	58 (51)	53 (48)

[1] These seeding rates are based on having a germination of 90% and an emergence of 85%–90% (plant stand of 76%–81% of seeding rate).

Recommended seeding rates are listed in Table 2–11, *Recommended Soybean Seeding Rates*, this page. The wider the row width, the lower the seeding rate required. These seeding rates are adequate for both conventional and no-till production. Rates can be reduced by 5%, when using precision seeding equipment compared to a seed drill. An emergence rate of 75%–80% is considered normal. Full yield potential is achieved in Ontario with final plant stands 309,000–370,000 plants/ha (125,000–150,000 plants/acre), depending on row width. Seeding rate must be adjusted upward for seed with a lower germination or vigour rating or for soils that tend to crust.

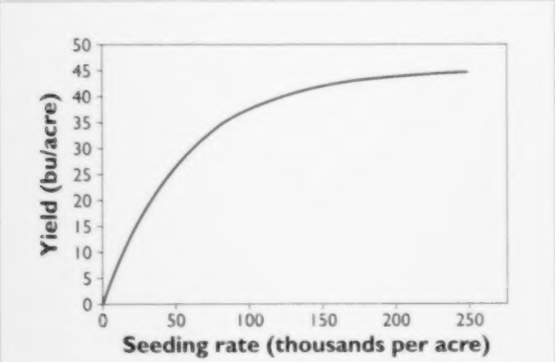


Figure 2–2. Soybean Yield Response to Seeding Rates
Values based on results from 45 Ontario trials in 38-cm. (7.5-in.) rows. Source: Earl, Bohner, University of Guelph, OMAFRA (2005–07).

Give special consideration to fields prone to white mould. Variety selection, wider rows and lower plant populations are the main tools available to minimize disease damage. Although wider rows and lower seeding rates will give up some yield in years when no white mould develops, this strategy can significantly reduce white mould severity during wetter summers. Grow fields prone to white mould with a minimum row width of 38 cm (15 in.) at 370,000 seeds/ha (150,000 seeds/acre). In fields with a severe history of white mould, consider using 76-cm (30-in.) rows.

Increase planting rates by 10% with late plantings into mid-June. Varieties respond similarly to changes in seeding rate. The formula for determining seeds needed per foot of row is:

$$\text{Seeds needed per m (ft) of row} = \frac{\text{Desired final plant population per m (ft) of row}}{\text{\% germination} \times \text{\% expected emergence}}$$

Seed size differences affect seeding rates. For each variety, seed size and seed quality are influenced by growing and harvest weather of the previous year. There can be as much as 20% variation in the seed size of a variety from one year to the next.

Table 2–12. Soybean Plant Stand and Yield Response to Seed Treatments

Seed Treatment[1]	Plants/ha (plants/acre)[2]	Yield[3] t/ha (bu/acre)
Control	345 000 (139 700)	3.3 (49.2) b
Fungicide	355 700 (144 000)	3.4 (50.4) a
Fungicide + Insecticide	369 500 (149 600)	3.4 (51.2) a

Least Significant Difference (P = 0.05) = 1.0 bu

Source: Hooker, Bohner, University of Guelph, OMAFRA.

[1] Values based on 35 seed treatment trials in Ontario.

[2] Plant stands taken at 30 days after seeding.

[3] Values followed by the same letter are not significantly different.

Seed Treatments

Soybean seed treatments have been shown to increase plant stands and improve yields in some situations. They can be an important tool in establishing a uniform plant stand especially in no-till, clay soils or early planted fields. Stand and yield response are dependent on the weather conditions following seeding and the level of disease and insects pressure. Of 35 Ontario trials conducted, 23% showed an increased plant stand with the use of a fungicide + insecticide seed treatment, while 17% of the trials increased yields. Table 2–12, *Soybean Plant Stand and Yield Response to Seed Treatments*, this page, shows average trial results. When conditions were favourable for quick emergence and little disease or insect pressure was evident, no yield benefit was found to soybean seed treatments. For more details on specific pests and control measures, see OMAFRA Publication 812, *Field Crop Protection Guide*.

Planting Depth

A seeding depth of 3.8 cm (1.5 in.) is generally adequate for soybeans. Early planting into no-till conditions can often be reduced to 2.5 cm (1 in.) if there is sufficient soil moisture. However, due to the high water demand for germination, plant 1 cm into moisture (approximately ½ in.), but never deeper than 6.4 cm (2.5 in.). A newly planted soybean seed is completely dependent on its reserve of energy to push through the soil. In general, larger seeds contain more energy and can be planted slightly deeper than small seed. Precise seed placement is difficult to achieve with some seed drills, especially in reduced or no-till fields. Adequate down pressure, ballast and the use of a coulter cart can help achieve proper seeding depth. It is important to have good seed-to-soil contact and a closed seed slot. The key is to plant into adequate soil moisture with a properly adjusted planter or drill. If seeding into moisture with a drill cannot be achieved, consider seeding with the planter, rather than waiting for rain.

Varieties differ in their ability to emerge from planting depths greater than 5 cm (2 in.). Seed companies can provide an "emergence score" or hypocotyl length rating, which rates the ability of the seedling to emerge from unusually deep planting.

Rolling

Rolling helps conserve moisture and prepare the field for harvest. Rolling can help level the soil and push rocks into the ground, making it possible to do a better job combining. Some producers roll immediately after planting, while others wait until the soybeans have emerged. Rolling immediately after planting provides improved seed-to-soil contact and reduces the likelihood of plant injury. However, it also increases the chance of soil crusting, which hinders soybean emergence. Soybean fields that are not rolled after the drill often emerge more quickly and uniformly. If rainfall occurs after seeding, rolled fields are more prone to crusting. However, if conditions are very dry, rolling can improve emergence because moisture is conserved.

Rolling soybeans after emergence does not reduce yields if:

- fields are rolled during the heat of the day to ensure that soybeans are limp. Soybeans are the most turgid (stiff) during the morning hours and rolling during that time will result in more plant injury.
- soybeans that are just emerging are left to grow until at least the unifoliate stage since seedlings are vulnerable to being broken off at emergence.

Soil Crusting

Crusting of the soil surface following a driving rain or ponding water can inhibit soybean emergence. The crust can break the hypocotyl arch (the portion of the plant that lifts the cotyledons above the soil surface). If soil is prone to crusting, plan to break the crust before the seedlings are attempting to break through.

Light tillage with a rotary hoe, harrows, coulter cart or even the planter or seed drill can help break the soil crust and aid bean emergence. Typically these operations can cause a 10% loss of emerged beans. A higher stand loss can occur when the hypocotyl arch is breaking the surface. "Crust-busting" may not be necessary in thin stands (e.g., 60%) where full yield potential already exists. See Table 2–13, *Expected Yield of Soybeans in Optimum and Reduced Stands*, next page, to determine yield potential.

Table 2–13. Expected Yield of Soybeans in Optimum and Reduced Stands

% of Full Stand	Expected Final Yield as % of Optimum	Plants per Hectare			
		18-cm rows (7-in.)	36-cm rows (14-in.)	53-cm rows (21-in.)	76-cm rows (30-in.)
100	100	553,300	402,600	392,700	405,100
80	100	442,100	323,600	313,700	323,600
60	100	331,000	242,100	237,100	244,500
40	87	222,300	160,600	158,100	163,000
20	62	111,200	81,500	79,000	81,500

Divide plants/ha by 2.47 to calculate plants/acre.

Source: University of Guelph, Huron Research Station and Kemptville College

Replant Decisions

Soybeans are more prone to poor stand establishment than corn or wheat, because the seedling must pull the cotyledon seed leaves through the ground to emerge. Deciding whether it is worth replanting a poor crop can be difficult. One of the main challenges in making a decision is that stand reductions are rarely uniform, so parts of a field may need to be treated separately. Do not assess a poor soybean stand too quickly, since more seedlings may still emerge. Fields with a plant reduction of 50% do not need replanting if plant loss is uniform and the stand is healthy. Numerous studies and field experience have demonstrated that keeping an existing stand is often more profitable than replanting. Replanting gives no guarantee of a perfect stand.

Every replant decision is based on factors surrounding the individual field. Information needed to make a replant decision includes:

- the population and health of existing stand. Normal seeding rates include a margin of safety to ensure emergence of an adequate stand.
- the cause of the low plant population. A number of factors can cause reduced soybean stands. These include soil crusting, herbicide injury, frost, hail, insects and diseases. For instance, in a wet year, damping-off is likely to be caused by two fungal classes — *Pythium* and *Phytophthora*. In this situation, if the stand is to be replanted, consider the use of a variety resistant to *Phytophthora* plus a seed treatment.
- the uniformity of the remaining plant stand
- the yield potential of the existing stand compared to the yield potential of the replanted stand. Yield potential begins to decline after the optimum planting date and declines throughout June.
- the cost of replanting and possibly additional weed control costs in thin stands

Compensation and Plant Spacing (Gaps)

Soybean plants have an amazing ability to compensate for thin stands. Soybean plants can fill interplant spaces up to about 30 cm (12 in.) within or between rows without any yield loss, provided weeds do not compete for this space. Ontario research has found that a 33% reduction in the stand, distributed uniformly over the field, will not significantly affect yield.

Plants in thin stands branch profusely, making them heavy and more prone to lodging. Branched plants tend to bear more of their pods near the ground. Consequently, harvest losses can be slightly higher in these stands. In trials with thin stands, lodging did not become a problem until populations dropped below 60% of a full stand.

Evaluating Stand Reductions

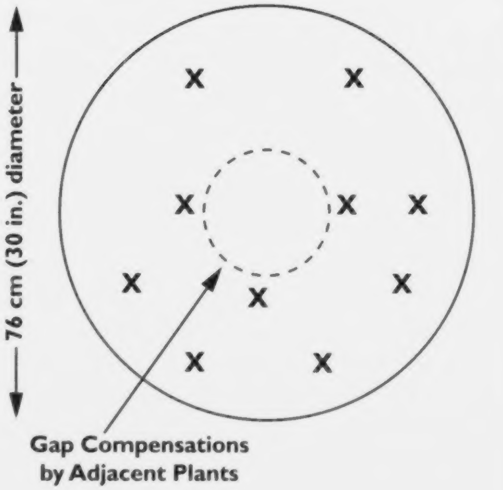
Accurately assess the stand for the population, spacing and health of the remaining plants. To determine plant population, see the hula-hoop method in Appendix K, *Hula Hoop Method for Determining Plant and Pest Populations*, on page 268.

Table 2–13, *Expected Yield of Soybeans in Optimum and Reduced Stands*, this page, provides an estimate of the yield potential compared to a full stand, based on research conducted in Ontario. It is important to note that Table 2–13 is based on the number of healthy plants remaining in a thin stand spaced uniformly and kept free of weed competition.

> Do not replant a plant stand of more than 222,000 plants/ha (90,000 plants/acre), in 19-cm (7.5-in.) row spacings on most soil types. Very heavy clay soils need a minimum of 250,000 plants/ha (110,000 plants/acre) before a replant is worthwhile.

Calculating Returns From Replanting

- Estimate the yield of a full stand with the original planting date.
- Determine the population of the existing stand. See the hula-hoop method described in Appendix K, *Hula Hoop Method for Determining Plant and Pest Populations*, on page 268.
- Estimate the yield potential of the reduced stand. See Table 2–13, this page.
- Estimate the yield potential of the replanted full stand. The later date will reduce the yield potential. See Table 2–7, *Effect of Planting Date on Yield and Plant Height*, on page 36.
- Estimate the cost of replanting
- Compare the value of reduced stand to replanted stand. (see Figure 2–3, *Reduced Stand in the Field*, opposite page).



Example

A field planted on May 12 is estimated to have a yield potential of 45 bu/acre if there were a full stand. On June 6, a reduced stand of solid-seeded, 18-cm-row (7-in.-row) soybeans has an average population of 222,220 plants/ha (90,000 plants/acre). The yield potential of this stand is 87% (39 bu/acre) of a full stand (Table 2–13). Yield expectation from replanting on June 6 would be about 38 bu/acre because of the later planting date (45 bu x 85% – from Table 2–7). Replanting would not be justified in this situation.

Figure 2–3. Reduced Stand in the Field

Patching or Thickening Thin Stands

In cases of poor stand establishment, replanting alongside the established seedlings to patch up or thicken the existing stand seldom improves yields unless the stand is very poor. If patching is contemplated, use the same variety and do not destroy the original stand. Repair planting often leads to timing difficulties with weed control and harvest date.

Plant Development

Table 2–14, *Vegetative Growth Stages in Soybean*, next page, and Table 2–15, *Reproductive Growth Stages in Soybean*, on page 43, show the growth stages of the soybean plant from emergence to full maturity.

The system used to describe soybean growth stages divides plant development into vegetative (V) — leaves and nodes — and reproductive (R) — flowers, pods and seeds — stages. The V stage refers to the number of nodes on the main stem with fully developed leaves, beginning with the unifoliate node. A leaf is considered fully developed when the leaflets on the next node have unrolled far enough so that their edges are not touching. For example, V1 refers to the stage when the unifoliate node has a fully developed leaf, meaning that the leaf above (first trifoliate) is unrolled. This stage is commonly referred to as the "first trifoliate" because the first trifoliate is unrolled. The node is the place on the stem where the leaf is or was attached. Trifoliate leaves on branches are not counted when determining V stages.

The first two leaves of the soybean plant are unifoliates (single leaflets) occurring opposite each other at the first node above the cotyledons. Subsequent leaves are trifoliate (three leaflets) and are on alternate sides along the stem. When the plant has 2–3 trifoliates, the nodules, which are important for the fixation of atmospheric nitrogen, become visible on the roots.

When planted at the optimal time, soybeans will develop 5–7 trifoliates before flowering begins. Flowering is triggered mainly by day length and temperature changes. Very early-maturing soybeans are nearly insensitive to day length. Instead, flowering is controlled mainly by accumulated heat units. Later-maturing varieties are influenced more by day length. Therefore, late-planted, long-season soybeans take fewer days to mature than those planted early.

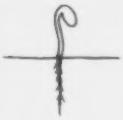
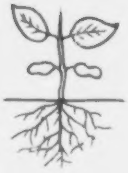
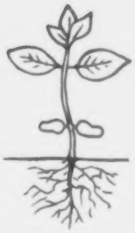
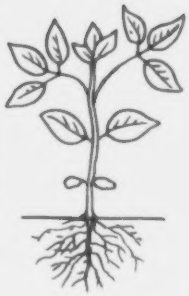
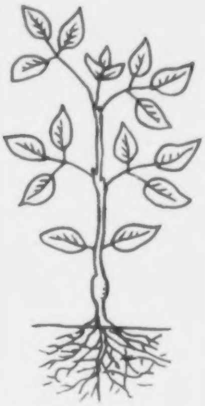
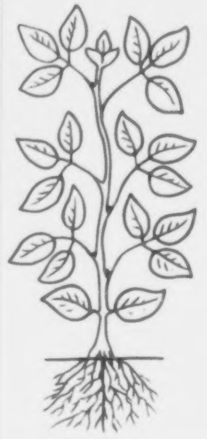
Germination and Emergence

Germination begins with the seed absorbing soil moisture until it reaches a moisture content of about 50%. The first external sign of germination is the emergence of the radicle (primary root), which grows downward and anchors itself in the soil. Shortly after, the hypocotyl (the section of the stem above the radicle) starts growing upwards, pulling the cotyledons (seed leaves) with it. Once emerged, the hook-shaped hypocotyl straightens out, the cotyledons fold down and the growing point is exposed to sunlight. Emergence normally occurs about 5–21 days after planting, depending on soil moisture, soil temperature and planting depth.

Most commercial soybean varieties in Ontario are indeterminate. Indeterminate varieties continue to grow taller and produce new leaves after flowering has commenced. Tall-determinate varieties grow to their full height before flowering begins. The flowering process occurs over a shorter period of time. Tall-determinate varieties characteristically have their lowest pods higher off the ground than indeterminate varieties.

Table 2–14. Vegetative Growth Stages in Soybean

(Not all V stages are presented here.)

						
Stage Abbreviated[1]	VE	VC	V1	V3	V5	Vn
Stage Title	Emergence	Unifoliate	First Trifoliate	Third Trifoliate	Fifth Trifoliate	Nth Trifoliate
Trifoliate Leaves	0	0	1	3	5	n
Days to Achieve Stage[2]	12	5	~ 5 days/fully expanded trifoliate leaf			~3 days/trifoliate leaf (V6–Vn)
Range in Days[3]	5–21	3–10	3–10	3–10	3–10	
Notes	• Seedlings emerge from soil, and cotyledons are above soil surface. • Emergence can be hindered by soil crusting.	• Hypocotyl straightens, cotyledons unfold. • Unifoliate leaves unroll so that leaf edges are not touching. • Growing point is above soil surface. • Frost can kill the plant. • Stem severed below the cotyledons will kill the plant.	• First trifoliate has emerged and opened (unifoliate leaves are now considered fully developed). • Start of critical weed-free period.	• 3 trifoliate leaves emerged and opened (3 nodes on main stem with fully developed leaves, starting with the unifoliate node). • End of critical weed-free period. • Nitrogen fixation has begun.	• 5 trifoliate leaves emerged and open (5 nodes on main stem with fully developed leaves, starting with the unifoliate node). • 50% leaf loss has little impact on final yield. • Early maturity soybeans reach R1 at approx. V4.	• n = number of nodes on the main stem with fully developed leaves, beginning with the unifoliate node. • The number of nodes is a function of maturity rating, planting date and climatic conditions.

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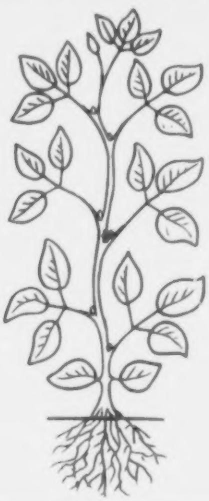
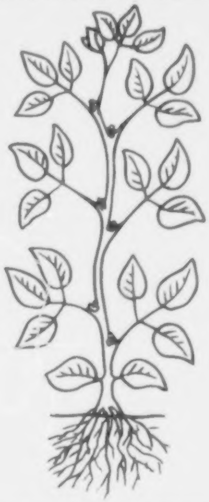
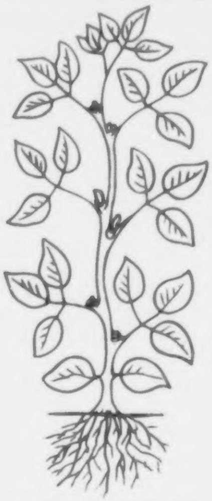
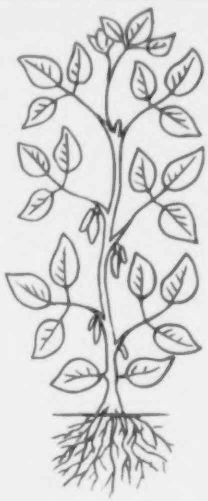
[1] V refers to the vegetative stages of soybean development. Vn = number of nodes on the main stem with fully developed leaves beginning with the unifoliate node. A fully developed leaf is defined as one that has a leaf above it (at the next node) with an unrolled leaf.

[2] An estimate of the number of days required to move from one stage to the next.

[3] Range is an estimate of days within a specific stage of development and is influenced by planting date, maturity rating and climatic conditions and can vary considerably within and between seasons.

Table 2–15. Reproductive Growth Stages in Soybean

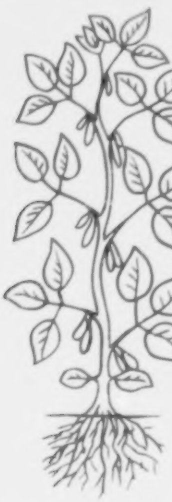
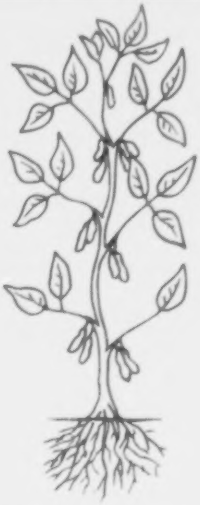
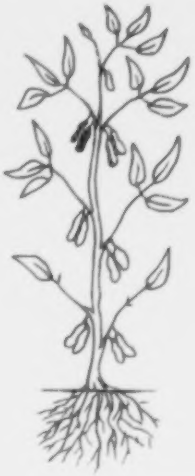
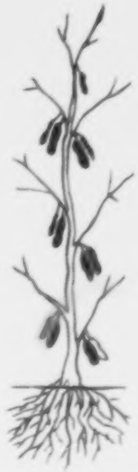
Each vegetative (V) or reproductive (R) stage is reached when 50% or more of the plants in a field of soybeans are at or beyond that stage.

				
R Stage[1]	**R1 – Beginning Bloom** One open flower visible from any node on stem.	**R2 – Full Bloom** Open flower on one of the top 2 nodes of main stem.	**R3 – Beginning Pod** Short pods visible at top 4 nodes of main stem with fully developed leaves.	**R4 – Full Pod** Pods 2 cm (.75 in.) long at top 4 nodes of main stem.
Target Event	Flowering	Flowering	Pod Development	Pod Development
Notes	• Triggered by changing day length and temperature. • Flowering begins near node 5 (V4) and moves up and down the stem. • Root growth rates increase. • Extreme heat (i.e., over 32°C) can reduce growth, flowering and pod development.	• 50% height and dry weight accumulation. • Stress does not usually reduce yield. • Nitrogen fixation increasing rapidly.	• Look for 2–3 seeds per pod. • Flowering peaks.	• Stress occurring between R4–R6 can result in significant yield loss.

[1] R refers to the various reproductive stages of soybean development.

Table 2–15. Reproductive Growth Stages in Soybean

Each vegetative (V) or reproductive (R) stage is reached when 50% or more of the plants in a field of soybeans are at or beyond that stage.

				
R Stage[1]	**R5 – Beginning Seed** Seed 0.3 cm long within upper (top 4) pods.	**R6 – Full Seed** Seeds within top 4 pods fill cavity in the upper pods.	**R7 – Beginning Maturity** One major pod has changed to brown colour on the main stem.	**R8 – Full Maturity** 95% of pods have changed to brown colour.
Target Event	Seed Development	Seed Development	Plant Maturity	Plant Maturity
Notes	• Flowering completed except for some branches. • Plant reaches max. height, nodes and leaf area. • Nitrogen fixation rates reach maximum and begin to decline. • Rapid nutrient uptake and redistribution to pods.	• Pods reaching full length. • Root growth slows substantially. • Above-ground dry weight accumulation slows. • Rapid leaf yellowing begins. • Leaves in lower canopy begin to fall.	• Moisture begins to decline in seeds. • Physiological maturity reached, maximum dry weight. • Seed moisture is about 60%.	• Harvest moisture reached in 1–2 weeks after R8.

[1] R refers to the various reproductive stages of soybean development.

Fertility Management

Nitrogen

Nitrogen fertilizers are not usually required for soybeans. (see *Inoculation*, on page 35). Research into nitrogen fertilizer applied at planting has shown that nitrogen, even in small amounts, can delay nodule fixation.

If nodulation does not occur, and the soybeans are pale green and N-deficient, the recommended remedial measure is to apply 50 kg/ha of N at first flower, as urea or calcium ammonium nitrate, when the foliage is dry.

Phosphate and Potash

Phosphate and potash recommendations for soybeans are given in Table 2–16, *Phosphate and Potash Recommendations for Soybeans Based on OMAFRA-Accredited Soil Tests*, opposite page. Occasionally, potassium deficiency will appear in soybeans as yellowing or browning of margins in older leaves (see Plate 14 on page 281).

For additional information about soil testing or soil test recommendations, see *Fertilizer Recommendations*, on page 158.

Methods of Application

Do not place fertilizer in contact with soybean seeds, due to the sensitivity to fertilizer salts. Unlike corn, there is no yield advantage to this practice. The fertilizer may be broadcast and plowed down or worked into the soil either in the fall or spring. A planter with a separate attachment for fertilizer placement may also be used to place the fertilizer 5 cm (2 in.) to the side and 5 cm (2 in.) below the seed. For further information, see Table 9–21, *Maximum Safe Rates of Nutrients*, on page 176.

Table 2–16. Phosphate and Potash Recommendations for Soybeans Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating[1]	Phosphate (P_2O_5)[2] Required kg/ha	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[2] Required kg/ ha
0–3	HR	80	0–15	HR	120
4–5		60	16–30		110
6–7		50	31–45		90
8–9		40	46–60		80
10–12	MR	30	61–80	MR	60
13–15		20	81–100		40
16–30	LR	0	101–120		30
31–60	RR	0	121–150	LR	0
61 +	NR[3]	0	151–250	RR	0
			251+	NR[3]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR, and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] Where manure is applied, reduce fertilizer applications according to the amount and quality of manure (see *Manure*, on page 144). Example of fertilizer application: If a soybean crop is not manured, and the soil tests are 9 for phosphorus and 85 for potassium, the phosphate requirement is 40 kg/ha and the potash requirement 40 kg/ha. These nutrients can be supplied by broadcasting or banding 200 kg/ha 0-20-20 fertilizer.

[3] For a nutrient that has an "NR" rating by soil analysis, the application of this nutrient in fertilizer or manure may cause problems due to reduced crop yield or quality. Phosphate additions may jeopardize water quality. Potash additions may induce magnesium deficiency on soils low in magnesium.

Plant Analysis

For soybeans, sampling the top fully developed leaf (three leaflets plus stem) at first flowering is recommended. See Table 2–17, *Interpretation of Plant Analysis for Soybeans*, this page. For sampling at times other than first flower, take samples from both deficient and healthy areas of the field for comparative purposes.

Take a soil sample from the same area and at the same time as a plant sample.

Micronutrients

Manganese

Manganese is the only micronutrient deficiency diagnosed in soybeans in Ontario, although zinc deficiency may show up in the future where the surface soil has been lost by erosion.

The symptoms of manganese deficiency are upper leaves ranging from pale-green (slight deficiency) to almost white (severe deficiency) with green veins (Plate 15 on page 281). Soil tests and plant analyses are useful in predicting where manganese deficiencies are likely to occur. Both are available at the OMAFRA-accredited laboratories listed in Appendix C, *Accredited Soil-Testing Laboratories in Ontario*, on page 260.

Table 2–17. Interpretation of Plant Analysis for Soybeans

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	4.0	6.0
Phosphorus (P)	%	0.35	0.5
Potassium (K)	%	2.0	3.0
Calcium (Ca)	%	–	3.0
Magnesium (Mg)	%	0.10	1.0
Boron (B)	ppm	20.0	55.0
Copper (Cu)	ppm	4.0	30.0
Manganese (Mn)	ppm	14.0	100.0
Molybdenum (Mo)	ppm	0.5	5.0
Zinc (Zn)	ppm	12.0	80.0

Values apply to the top fully developed leaf (3 leaflets plus stem) at first flowering.

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

To correct a manganese deficiency, spray the foliage with 2 kg/ha of actual manganese (8 kg/ha of manganese sulphate) in 200 L of water. A "spreader-sticker" in the spray is recommended. If the deficiency is severe, a second application may be beneficial.

> **Caution:** When applying micronutrients with a sprayer that has been used to apply herbicides, it is essential to clean out the spray tank to avoid crop injury. See Chapter 12, *Weed Control*, for more details.

Soil application is not a recommended method of applying manganese, regardless of the source, due to the large amounts required. Application of manganese chelates to the soil has resulted in yield reductions.

In general, beans will give a profitable response to manganese in the parts of the field where manganese deficiency is evident. There is no benefit to applying manganese to beans without deficiency symptoms.

Harvest and Storage

Minimize Harvest Losses

Soybeans are direct combined, preferably with a combine equipped with a floating flexible cutterbar and automatic header height control. Soybeans can be harvested at moisture levels below 20%, but they must be stored at 14% moisture or lower.

Harvest losses and mechanical damage may be high when soybeans are harvested below 12% moisture. A loss of just 4 beans/900 cm^2 (4/ft^2) represents an overall loss of 67 kg/ha (1 bu/acre). Losses can be minimized if a ground speed of 4–5 km/h is maintained. The reel speed should be adjusted to match crop conditions.

A floating cutterbar can be used to cut the soybean plants off, closer to ground level. Adjust the cleaning fan to provide maximum air without blowing soybeans into the return elevator or out the back end. Adjust the chaffer to allow the fan to separate pods and stalk pieces from the soybeans. Adjust the sieve to allow only soybeans through. Adjust the air speed, chaffer and seive settings throughout the day as the weather conditions and soybeans change.

Header maintenance is important. The majority of soybean losses occur at the header. The cutter bar must be sharp, and the knife sections must make good contact with the guard ledger plates to allow quick cutting action and rapid movement of the cut beans into the header. Add belting to the bat reel, or use an air reel to get short beans into the feed auger quickly.

If soybean plants remain standing and uncut behind the header:

- check blades and guards
- consider reducing ground speed

Quality and Identity Preservation (IP)

Preharvest

If the soybean crop is destined for an identity-preserved (IP) market, make a special effort to maintain seed quality. Staining and mechanical damage are the main problems at harvest that can downgrade quality. Mechanical damage can result in an entire load being rejected. Staining can occur from weeds, immature beans, dirt and dust. Prior to harvest, thoroughly clean combines, trucks, wagons and other handling equipment and bins to prevent contamination. Scout and rogue fields for off-types and other volunteer crops (e.g., corn). Check fencerows and roadsides for glass, metal, fence posts and other trash. Harvesting of IP beans must wait until soybean stems and weeds have dried down completely to avoid green staining of the seed. Remove weeds such as Eastern black nightshade and American pokeweed from the field before harvest, or have the combine operator avoid weed-infested areas.

Harvest and Storage

When harvesting IP beans that are a different variety from the previous field harvested, it is best to thoroughly clean out the combine from top to bottom to remove trapped beans. An alternative, although less-effective, method of combine cleaning involves combining a small area of IP beans separately and loading them into a "slush" wagon. The sample can be used to check moisture and combine set-up. Other harvest tips include:

- Oversee custom harvesters to make sure their equipment is ready to harvest.
- Keep a copy of the IP contract on hand to determine the quality parameters at harvest. IP harvesting starts later and ends sooner in the day than for commercial beans, mainly to prevent staining. Once contaminated, a combine is difficult to clean.
- It is best to harvest at moisture levels close to 14% to avoid the need for anything other than ambient air drying. Harvesting at or above 12% moisture, and gentle handling, are necessary to avoid cracked seed coats.
- Adjust the combine to varying harvest conditions throughout the day. Adjustments to reduce mechanical damage may increase dockage (pick) but are more than compensated for by premiums.
- Store IP soybeans in separate bins that are free of other soybean varieties and other grains and oilseeds.

If the crop was produced under contract, all of these requirements will be outlined in the signed agreement. With or without a contract, failure to comply can result in lost premiums.

Soybean Drying

Grain Dryers

The three basic general types of grain dryers used on the farm are:

- in-bin
- batch
- continuous flow

These three broad groups of crop driers can be further broken down into different types. No single drying system is superior to all others in every respect. System selection is dependent on desired features. These features include drying capacity, grain quality, fuel/drying efficiency (BTU/lb of water removed), convenience, manpower required to run the dryer, ability to dry a variety of crops, maintenance required and capital cost.

All dryers move heated air past the grain to evaporate moisture from the grain and carry the water vapour away. Heat is added to this drying air to reduce its relative humidity, thereby increasing its ability to pick up moisture. Wet grain can be dried at higher temperatures since it will be cooled as the moisture evaporates from the kernels. As the grain dries, it will approach the temperature of the drying air. The longer the grain kernels are in contact with this heated air, the drier and hotter the kernels will get.

Drying Soybeans With Heated and Unheated Air

Soybeans are sometimes harvested at a higher moisture content due to wet weather or are harvested earlier than expected to reduce combine losses. All drying methods are adaptable to soybeans with some restrictions on the use of heat and handling practices.

Take care when using heated air to dry soybeans that are higher in moisture than desired for safe, long-term storage. The relative humidity of the drying air must be kept above 40% to prevent seed coats from splitting. Experience has shown that with as little as 5 minutes exposure to high heat, it is possible to cause 100% of the soybeans to crack. Most recommendations for drying commercial soybeans suggest a maximum temperature of 55°C–60°C. In good drying weather, you may need to reduce this drying temperature to control seed coat cracking. Check the number of split seeds before and after drying to gauge the drying effect.

Seed soybeans should be dried at temperatures below 40°C. This should only be attempted after several years of experience. Some seed companies frown on the use of any heat in conditioning seed soybeans. Ask your seed company what method of conditioning it allows or prefers for seed beans.

With bin dryers, use caution in any system that involves moving the soybeans in the bin with re-circulators or stirrators. Damage from handling can be severe, especially as the moisture content drops to 12%.

Natural-Air Drying

Tough soybeans can be dried with natural air under good drying conditions. Natural-air drying of soybeans requires careful management by the operator, since soybeans give up and take on moisture easily. The fan must be run only when the outside conditions will result in drying progress. Do not run the fan continuously, night and day, as re-wetting will occur at night, reversing any progress made during the day.

Minimum Requirements for Natural-Air Drying Soybeans

- full aeration floor in the bin
- level soybean surface across the whole bin
- minimum airflow of 6.5 L/sec/m^3 (0.5 CFM/bu), preferably more
- clean beans with no pods or fines accumulations
- accurate moisture reading of the beans in the bin
- accurate outside air temperature and relative humidity measurement
- an understanding of soybean equilibrium moisture content
- an on/off switch for the fan

A full aeration floor is essential to move air uniformly through the entire bin contents. With a partial aeration floor or air duct system, dead areas will exist, leading to potential spoilage problems. Bean pods, trash and fines accumulations in the bin will restrict or divert airflow. Air moving through the bean mass will take the path of least resistance.

Determining Airflow

Sufficient airflow is needed to move drying air through the whole bean mass. To remove moisture, the minimum airflow required is 6.5 L/sec/m^3 (0.5 CFM/bu). Anything less will only change temperature but will not change moisture content of soybeans. Higher airflow rates of 26 L/sec/m^3 (2 CFM/bu) or greater, only get the job done quicker. In order to determine the CFM/bu value for a bin, determine the number of bushels in the bin and the static pressure that the fan is operating

Table 2–18. Equilibrium Moisture Content (% Wet Basis) for Soybeans Exposed to Air

Temperature (°C)	Relative Humidity (%)				
	50	60	70	80	90
0	10.0	11.8	13.7	16.2	19.8
5	9.8	11.5	13.5	15.9	19.6
10	9.5	11.2	13.2	15.7	19.4
15	9.2	11.0	13.0	15.5	19.2
20	9.0	10.7	12.8	15.2	19.0
25	8.7	10.5	12.5	15.0	18.8

against. A simple manometer connected to the air plenum below the perforated floor will display the static pressure in inches of water column (see Figure 11–1, *Home-Built Manometer*, on page 183). Determine fan output at the measured static pressure by using the fan performance curve. Divide the CFM output of the fan by the number of bushels in the bin to give the CFM/bu airflow. One strategy to get adequate airflow is to only partially fill the bin. This way, the fan will be operating at less static pressure and deliver higher airflow rates per bushel.

Equilibrium Moisture Content

Researchers have developed equilibrium moisture content tables that aid in predicting the final moisture content of soybeans when exposed to air at a certain temperature and relative humidity (see Table 2–18, *Equilibrium Moisture Content (% Wet Basis) for Soybeans Exposed to Air*, this page). To determine, for example, the equilibrium moisture content of soybeans exposed to outside air at 10°C and 70% relative humidity, find the point at which the 10°C row and the 70% relative humidity column intersect. This point will be the equilibrium moisture content for soybeans. Given enough time, the soybeans will dry down to 13.2% moisture content.

Measuring Relative Humidity

Accurately measuring the relative humidity of the outside air presents a bit of a challenge. In some cases, this reading can be obtained from a nearby weather station. It is important to determine if a nearby weather station is an accurate reflection of conditions at a specific location. To air-dry soybeans, it is important to know the accurate relative humidity of the outside air. Household hygrometers tend to be inaccurate and are not recommended for measuring relative humidity when air-drying tough beans. A sling psychrometer or a good quality hygrometer are recommended for this purpose.

When to Run the Fan

Fan operation is not limited by the time of day but rather by air temperature and relative humidity levels. On some days, drying can be accomplished from 9 AM until midnight, while on others it may only be from 9 AM to 6 PM. Check the temperature and relative humidity of the air numerous times throughout the day. The outside air must be drier than the inside air for making drying progress. If the equilibrium moisture content on a given day is less than the moisture content of the wettest beans, drying is possible, and the fan should be on. Humidistats are available that will activate the fan at pre-set humidity levels. The operator can adjust the relative humidity level at which the fan is activated.

The beans at the top of the bin will be the last to dry. Each day of fan operation will push a drying front up through the bin. This drying front may not reach the top of the bin as quickly as expected. Be sure to take moisture samples at the same depth each time to know how the moisture content is changing at that depth. Bins with stirrators will have fairly uniform moisture levels throughout the whole bin.

Other Crop Problems

Insects and Diseases

Figure 2–4, *Soybean Scouting Calendar*, opposite page, shows insects and diseases that could be causing the symptoms in the field. Individual descriptions of insects and diseases, scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, or Chapter 14, *Diseases of Field Crops*.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

Frost and Hail Damage

Early Season

Plants damaged below the cotyledons by early-season frost or hail will not recover. If frost or hail damages the growing point of the seedling, but not the stem portion below, the plant will send out new shoots from the base of the leaves or cotyledons (Plate 16 on page 281). Wait 3 or 4 days and watch for new growth to emerge from the point where leaves attach to the stem (leaf axils). Research trials show that leaf loss at early growth stages has little impact on final yield or maturity. Table 2–19, *Percent Yield Loss of Indeterminate Soybean at Various Levels of Leaf Area Loss and Growth Stages*, on page 50, summarizes the expected yield loss from leaf loss at various life stages.

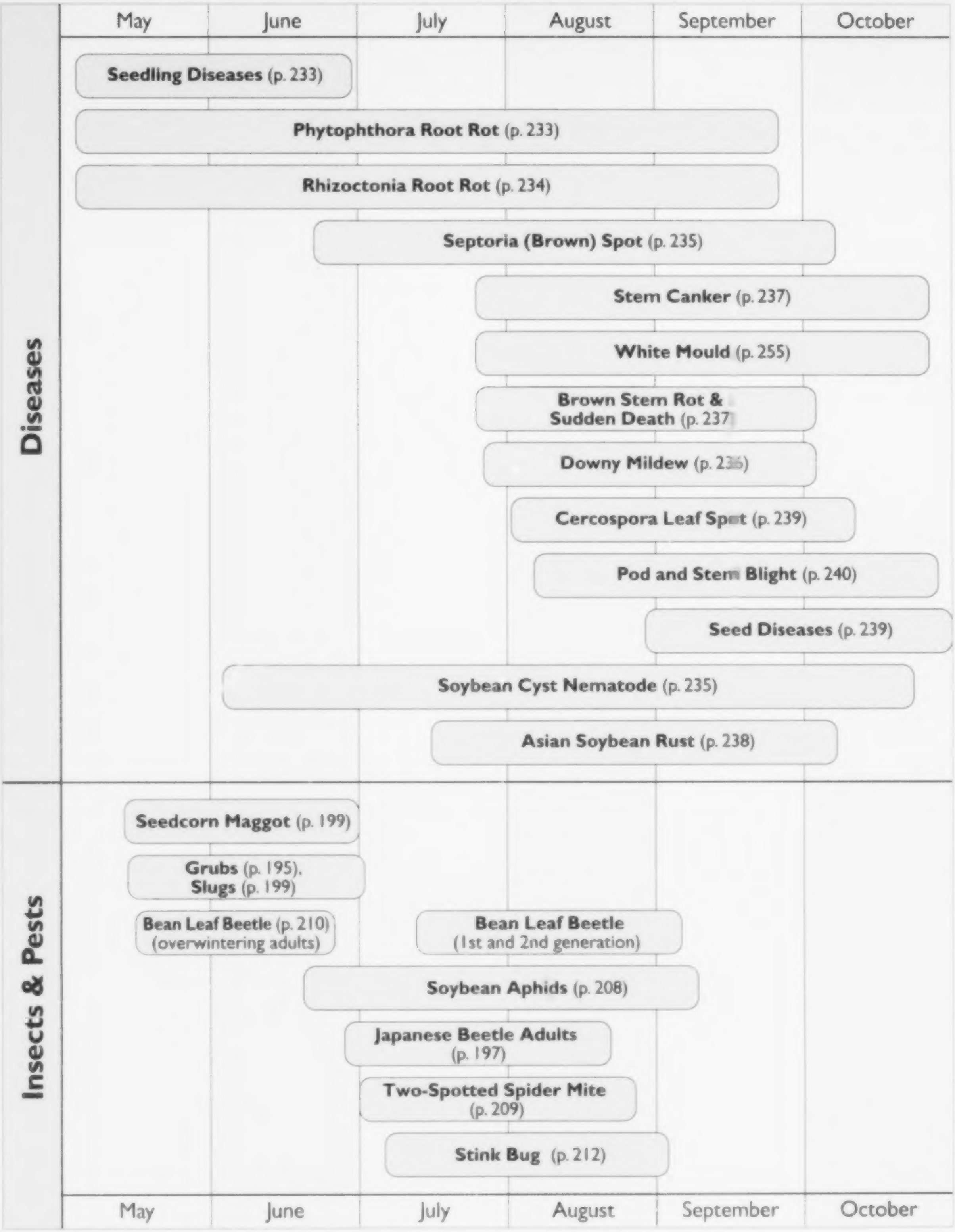


Figure 2–4. Soybean Scouting Calendar

Table 2–19. Percent Yield Loss of Indeterminate Soybean at Various Levels of Leaf Area Loss and Growth Stages

Growth Stage	Percent Leaf Area Destroyed									
	10	20	30	40	50	60	70	80	90	100
VC–Vn	–	–	–	–	–	–	–	–	–	–
R1	–	1	2	3	3	4	5	6	8	12
R2	–	2	3	5	6	7	9	12	16	23
R2.5	1	2	3	5	7	9	11	15	20	28
R3	2	3	4	6	8	11	14	18	24	33
R3.5	3	4	5	7	10	13	18	24	31	45
R4	3	5	7	9	12	16	22	30	39	56
R4.5	4	6	9	11	15	20	27	37	49	65
R5	4	7	10	13	17	23	31	43	58	75
R5.5	4	7	10	13	17	23	31	43	58	75
R6	1	6	9	11	14	18	23	31	41	53
R6.5	0	1	1	3	4	5	7	13	18	23

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Stem Damage

Broken or cut-off stems have greater impact than leaf loss on yield and maturity. If stem loss is under 50% prior to flowering, yield loss will be less than 10%. When evaluating hail damage, check for bruising on the plant stem. Severe damage to the stem will make it more difficult for the plant to recover (Plate 17 on page 281). It can also make the plant more susceptible to disease. Bruising, which does not cause stem breakage, causes minimal loss in yield.

In terms of yield reduction, soybeans are most vulnerable during the flowering and seed fill period. This is particularly true if stems are broken, resulting in a reduction in the number of pods. Delays in maturity and seed size also occur.

Late Season Cold Temperature and Frost Injury

Soybeans are regarded as a warm-season crop and are therefore more susceptible to cold temperatures, especially during flowering. It is believed that sustained cold temperatures (less than 10°C) during flowering affect proper formation of pollen in the flower. This results in poorly developed pods called parthencarpic pods (also called "monkey pods"). There is some variety difference in tolerance to cold temperatures.

Varieties that have tawny pubescence (i.e., yellowish-brown hair) are often more cold tolerant than those that have grey pubescence.

Frost during flowering and pod fill can drastically reduce yield and quality. A severe frost during these stages can reduce yield by up to 80%. Freezing during pod fill will result in severely damaged beans with a greenish, "candied" appearance. Even moderately frosted beans with a greenish colour and slightly wrinkled seed coat are considered damaged and can be discounted if present in excess of limits. The seed will eventually dry down with a wrinkled seed coat. Frost-injured plants may reach maturity earlier but will have seed moisture equal to non-frosted plants. Germination will also be severely reduced. The Canadian Food Inspection Agency classifies frost-damaged soybeans as those "soybeans whose cotyledons, when cut, are green or greenish-brown in colour with a glassy, wax-like appearance."

Yield reductions from late season frost injury are smaller as the crop matures. Frost during the R5 stage reduces yield by 50%–70%. Frost at the R6 stage will cause losses of 20%–30%. Once the crop reaches the R7 stage only a 5% yield loss is expected. No yield reductions occur once the plants have reached full maturity.

Lightning Damage

Lightning damage is confined to small circular or oval regions with a diameter of 5–10 m. Plants are usually killed but can sometimes survive on the edges of the affected area. The affected area has a clearly defined margin, making diagnosis relatively straight forward (Plate 18 on page 281). The affected area does not grow over time. Stems are often darkened with dead leaves remaining attached to the plant.

Mature Green Seed

An extremely dry growing season can result in green soybean seed at harvest even if seed moisture is below 13% (Plate 19 on page 282). The problem is generally the most severe in those regions that are extremely dry during July and August in soils with poor water holding capacity. Since the beans are dry, the "activity" inside the seed is minimal. The enzyme that normally breaks down the chlorophyll cannot function at such low moistures, therefore the green colour will not disappear over time. There may be some improvement to the green tinge on the outside of the bean over time, but the green discolouration inside the bean will remain if left in the field or in storage. There is little that can be done to avoid having green beans since this problem is weather related. A good crop rotation along with choosing the best varieties suited for the area is the best defence.

Forages

3. Forages

Forages are a major Ontario crop, using over one-third of Ontario's improved land. Hay and haylage are grown on 1,012,000 ha (2,500,000 acres), while there are 303,500 ha (750,000 acres) of seeded pasture and 445,000 ha (1,100,000 acres) of natural pasture. Approximately 129,500 ha (320,000 acres) of corn silage is grown in Ontario — 17% of the corn crop. The value of forage production is estimated to be about 10% of the agricultural production in Ontario.

Forages are whole plants harvested for livestock feed. They are an important component of crop rotations on many farms, and their benefit has been demonstrated by numerous research trials and grower experience.

Crop management is more complex with forages than with many other crops, for several reasons:

- Forage usually consists of a mixture of different species.
- Forage may be used as either stored feed or pasture.
- There is a wide range of harvest and storage systems used.
- Perennial crops require management to ensure over-winter survival.

For information on corn silage production, see *Selecting Hybrids for Silage*, on page 11. Information on corn silage harvest and storage is discussed in *Haylage and Corn Silage*, on page 73. For more detailed information on pasture, see OMAFRA Publication 19, *Pasture Production,* or the OMAFRA website at www.ontario.ca/crops.

Species

Perennial Legumes

Most legumes grown for forages have taproots and broad, compound leaves (composed of a number of leaflets) that are arranged alternately on the stem. New shoots originate from the crown of the plant, and the growing point of each shoot is located at the top of the shoot. As a family, legumes produce higher quantities of protein than grasses.

If properly inoculated, legumes have the capacity to use atmospheric nitrogen, eliminating the need to apply nitrogen from commercial sources. Legumes also supply a considerable amount of nitrogen to the grass portion of the mixture.

Alfalfa

Alfalfa is the highest-yielding perennial forage crop grown in Ontario and the most frequently grown forage legume. It produces more protein per unit area than other forage legumes and can be grown alone or in combination with various grass species. For high yields and persistence, alfalfa requires well-drained soil, a pH above 6.1, adequate fertility and proper harvest management. Well-managed alfalfa normally persists for 3 or more years. The protein and energy levels of alfalfa-based forage are determined by stage of growth at the time of cutting. Alfalfa has a 6-week critical fall harvest period that should be observed to avoid winterkill.

Birdsfoot Trefoil

Birdsfoot trefoil is a non-bloating legume best suited for permanent pasture situations. It will reseed itself, making it an excellent choice for steep or stony land not suited to cultivation. Although individual plants live for only a few years, stands of birdsfoot trefoil have remained productive for 10 or more years when allowed to go to seed. It is also well adapted to soils with marginal drainage. Birdsfoot trefoil has a lower yield potential and is more difficult to dry than alfalfa, so it is recommended for hay production only in areas where alfalfa will not grow well. Since birdsfoot trefoil seedlings are slow to establish, at least a year is required to get a satisfactory stand. Birdsfoot trefoil, similar to alfalfa, has a critical fall harvest period, beginning about 10 days earlier than alfalfa.

Red Clover

Red clover is a short-lived perennial. Yields are good the year after establishment but are often quite low the following year, especially in Southern Ontario. It can be grown in fields that are too wet or acidic for alfalfa. When seeded in mixtures, red clover can suppress the establishment of other legumes. As a feed crop, red clover is most often stored as silage since it is difficult to dry, and often results in "dusty" or "mouldy" hay.

There are two general types of red clover grown in Ontario: double-cut or "medium" red clover and single-cut or "mammoth" red clover. Double-cut will flower in the seeding year, with vigorous regrowth after cutting. Single-cut is slower growing and matures about 2 weeks later than double-cut. Single-cut does not flower in the seeding year or after the first cut in succeeding years.

Use of red clover as a plowdown has become an important practice on many farms. See Chapter 8, *Soil*

Management, for information on the use of red clover as a cover crop.

White Clover

White clover is used mainly in pastures. It is a short-lived perennial that can reseed itself. There are three general types of white clover: ladino, white dutch and small wild white. All three are similar in appearance but differ in size, with wild white being the smallest and ladino the largest. All have stolons, which are stems that creep on the ground, with branches that are erect or upward slanting. Roots are shallow and fibrous and develop from nodes of the creeping stolons. White clover has low tolerance to drought but is relatively tolerant to frequent grazing and has good palatability. White clover can be frost seeded or no-tilled into existing grass pastures to improve forage quality and yield.

Sweet Clover

Sweet clover is a slow-growing biennial often used to alleviate compaction. Sweet clover does not flower in the year of establishment. In the spring of the second year, it grows quickly to become a tall, coarse-stemmed plant. The presence of coumarin in sweet clover makes it less palatable to livestock.

There are two types of sweet clover: white-flowered and yellow-flowered. White sweet clover is deeper rooted, taller and coarser, which makes it more suitable for plowdown than for forage. The yellow-flowered is more palatable to livestock and more attractive to bees. **Mouldy sweet clover hay may contain dicoumarol, which can prevent normal blood clotting and result in the death of livestock from bleeding.**

Alsike Clover

Alsike clover is a perennial although it is often treated as a biennial. It can grow on soils that are acidic and poorly drained. Alsike produces only one cut of hay per year and is not normally a preferred forage legume. **Alsike clover can cause photosensitivity and liver damage in horses, so it should not be included in horse hay or pasture mixtures.**

Kura Clover

Kura clover is a pasture legume relatively new to Ontario. Kura clover has poor seedling vigour and is difficult to establish. However, once established, kura clover is very persistent, winter-hardy and can tolerate less-than-ideal drainage, fertility, pH and grazing management. It spreads by underground stems called rhizomes, has an extensive root system and thickens with time. Proper seedbed preparation and seeding methods are important. Kura clover must be inoculated with the correct strain of *Rhizobium* bacteria.

Perennial Grasses

Grasses have many long, slender leaves that are borne on a stem. They have very fibrous roots that help bind the soil together, thereby reducing erosion. Some grasses have rhizomes or underground stems that produce new shoots at each node. Grasses with rhizomes are capable of thickening up a stand. Grasses without rhizomes are known as bunch grasses.

Grass species differ in their competitiveness with legumes. This will influence the grass-to-legume ratio of an established stand. Grasses such as orchardgrass and the ryegrasses tend to be more competitive with alfalfa than timothy or bromegrass. Grasses are lower in protein than legumes when cut at a similar stage of development.

Timothy

Timothy is the most widely sown forage grass in Ontario and is commonly grown in mixtures with alfalfa or birdsfoot trefoil. It is a bunchgrass with limited tillering ability, which makes it non-aggressive when sown with other species. It is easy to establish in early spring or late summer and is adapted to heavier soils and variable drainage. Timothy is palatable and high yielding in first cut. Although some varieties have been developed for improved regrowth, regrowth after first-cut and mid-season production is not as high as that from either bromegrass or orchardgrass.

Smooth Bromegrass

Smooth bromegrass is an earlier, more aggressive grass than timothy. Better drought tolerance results in more regrowth in second cut. It spreads by rhizomes, and the stand can thicken over time. Smooth bromegrass is palatable and tends to retain its nutritional value with increasing maturity better than most grasses. Its major drawback tends to be its large fluffy seed, which makes it difficult to seed through the small seed box of drills. It does not establish well if it is either surface seeded or seeded deeper than 5 cm (2 in.).

Meadow Bromegrass

Meadow bromegrass is useful as a pasture species because of its early spring growth and faster recovery rate after grazing. It is best used in rotational grazing.

Orchardgrass

Orchardgrass develops earlier and is much more aggressive than timothy or bromegrass. It is palatable when young but loses palatability and digestibility more quickly than other grasses. Plant breeders have developed newer varieties that are later maturing, do not decline in palatability and digestibility as early and match more closely the maturity of other species in a mixture. Orchardgrass will grow much more vigorously in the warm, dry conditions of midsummer than timothy or bromegrass, resulting in a greater proportion of grass in the second and third cutting of alfalfa-grass mixtures. Orchardgrass is not as winter-hardy as either timothy or bromegrass and will not persist in wet soils. Its aggressive seedlings make orchardgrass easy to establish. It is recommended for intensively managed pastures or as very early-cut haylage.

Reed Canarygrass

Reed canarygrass is best known for its ability to tolerate poorly drained soils. It can, however, provide high yields on well-drained soils and will produce higher yields than other grass species during dry conditions. Reed canarygrass spreads by rhizomes. It develops coarse stems and leaves, and quickly loses palatability and digestibility after heading. Regrowth is vegetative and does not form a seed head, so second- and third-cuts can be high quality. Reed canarygrass is slow to establish and is not competitive in the year of seeding.

In the past, livestock have performed poorly on reed canarygrass because of certain alkaloids it contained. Current recommended reed canarygrass varieties are free of tryptomine and carboline alkaloids, which cause poor performance. Some varieties are lower in the gramine alkaloids that reduce palatability, intake and animal performance.

Tall Fescue

Tall fescue is a coarse, leafy grass that is useful in long-term pastures and erosion control. It is adapted to most soil types, tolerates imperfect drainage and withstands animal traffic well. Its ability to maintain good feed quality into late fall makes it useful in "stockpile grazing" or fall-saved pasture for deferred grazing. A seed-borne systemic fungus (an endophyte) has been linked to poor animal performance on tall fescue pasture. Once introduced by infected seed, the fungus cannot be controlled in an established stand of tall fescue. All recommended varieties are endophyte-free.

Meadow Foxtail

Meadow foxtail is a long-lived perennial grass that resembles timothy in appearance and is suitable for intensive pasture management. It performs well on poorly drained soils, has very early spring growth and matures early. Midsummer production during periods of high temperature and drought may be low. Its seed is light, fluffy and hairy; coated seed should be used.

Creeping Red Fescue

Creeping red fescue is a dense, sod-forming grass that establishes and spreads vigorously on most soil types, including well-fertilized subsoils. Its solid root system and thick, fine top growth make creeping red fescue an excellent grass for streambank or grass waterway protection. It can also serve as a bottom grass in long-term pastures and is noted for its extended growth period and retained nutritional value in the fall. Its low-growing habit makes it difficult to cut and unsuitable for hay.

Meadow Fescue

Meadow fescue is a hardy grass used in hay and pasture mixtures. It grows best on deep, fertile soils, but will tolerate variable drainage and low fertility. Meadow fescue yields well during the summer and fall and maintains its feed quality later into the season than most grass species. Meadow fescue is shorter, has finer leaves and a shallower root system than tall fescue and is not as persistent.

Perennial Ryegrass

Perennial ryegrass is a short-lived perennial that comes in turf, pasture and hay-adapted varieties. The pasture-adapted varieties tend to have finer leaves, smaller and more numerous tillers, and are later maturing than the hay varieties. Turf-type perennial ryegrasses contain endophytes, so they should not be used for forage. Perennial ryegrass is early and vigorous in the spring, and grows well into the fall, but is unproductive during the hot, dry summer months. Excessive top growth of perennial ryegrass can result in winterkill, in alfalfa mixtures that are left to over-winter. Perennial ryegrass is not well suited to areas with prolonged ice cover and extreme cold without adequate snow cover.

Bluegrass

In Ontario, two common bluegrasses, Canada and Kentucky, grow on approximately 400,000 ha (1 million acres) of permanent pastureland. In Southern Ontario, the shallow-rooted bluegrasses produce lush, palatable growth during the spring but are unproductive during the dry, hot summer. When properly fertilized and managed, bluegrass production can be markedly improved, especially under the cooler climate of northern Ontario. In pastures, they serve as a bottom grass that controls weed invasion, withstands close grazing and tramping, and fills in when other species thin out.

Table 3–1. Characteristics of Perennial Forage Species Grown in Ontario

Species	Suitability	Persistence (years)	Strengths	Cautions
Legumes				
Alfalfa	Stored feed	3–4 S. Ont. 1–4 N. Ont.	Excellent quality Excellent yield	May cause bloat Poor persistence under grazing Low tolerance to acidic or variably drained soil Needs fall rest period
Birdsfoot trefoil	Pasture Stored feed	5+ (may reseed itself)	High quality No bloat hazard Good tolerance to acidic & variably drained soil	Slow to establish Slow spring growth and regrowth Needs fall rest period Unpalatable to horses
Red clover	Pasture Stored feed Plowdown	1–3	Excellent first-year yield Easy to establish High quality Good tolerance to acidic or variably drained soil	Difficult to dry for hay May cause bloat Stand thins rapidly May cause temporary infertility in grazing sheep Very competitive, especially with other legumes
White clover	Pasture	5+	Excellent quality and palatability Good tolerance to close grazing	May cause bloat Low drought tolerance
Kura clover	Pasture	5+	Persistent High quality	Difficult to establish May cause bloat
Alsike clover	Pasture Stored feed	1–2 (may reseed)	Very good tolerance to wet, acidic soils Good quality	Lower yield than red clover Regrowth yields low Stand thins rapidly May cause bloat
Sweet clover	Plowdown Stored feed	2	Excellent soil builder Opens up subsoil Excellent bee pasture	Low palatability unless harvested early Coumarin content in older varieties causes feeding difficulties Only 1 harvest-year
Grasses				
Timothy	Stored feed	5+	Easy to establish Good tolerance to variable drainage Seed is inexpensive	Poor summer production Poor persistence of late-heading varieties under three-cut harvest system
Smooth bromegrass	Pasture Stored feed	5+	Excellent spring/fall yield Good regrowth Better quality retention with maturity	Large seed size may cause seeding challenges
Meadow bromegrass	Pasture Stored feed	5+	Early spring growth Fast recovery after cutting or grazing Good winter-hardiness Good palatability	Large seed size may cause seeding challenges Sensitive to flooding Spreads less by rhizomes than smooth bromegrass
Orchardgrass	Pasture Stored feed	5	Very early pasture Excellent regrowth Good drought tolerance Good tolerance to close grazing Very responsive to nitrogen	Rapidly loses quality and palatability with maturity Very competitive with other species Poor tolerance to variable drainage and icing
Reed canarygrass	Pasture Stored feed	5+	Excellent yield on both variably drained and dry soils Good regrowth Very responsive to nitrogen	Slow to establish First-cut rapidly loses quality and palatability with maturity Poor tolerance to close grazing or frequent cutting
Creeping red fescue	Pasture Grass Waterways	5+	Good feed quality in fall Easy to establish Good tolerance to close grazing and to acidic soils Good regrowth	Low seasonal yield Low palatability

Table 3–1. Characteristics of Perennial Forage Species Grown in Ontario

Species	Suitability	Persistence (years)	Strengths	Cautions
Meadow fescue	Pasture Stored feed	5+	More suitable for managed gazing than as stored feed Grows in early spring and late fall Tolerant to variably drained soil More palatable than tall fescue Prevents erosion in waterways	Coated seed required Very competitive with other species Low drought tolerance Low quality with maturity Less persistent and lower yielding than tall fescue
Tall fescue	Pasture Stored feed Grass Waterways	5+	High yield Good summer growth Good feed quality in fall for stockpile grazing Good tolerance to acidic soil	Coarse leaves and low palatability Need endophyte-free seed
Perennial ryegrass	Pasture Stored feed	2–3 S. Ont.	Excellent quality and palatability Establishes very quickly Good tolerance to close grazing	Poor drought and heat tolerance Poor tolerance to variably drained soils Variable persistence
Kentucky bluegrass	Pasture Grass Waterways	5+	Good quality and palatability Good tolerance to close grazing	Poor summer production Very slow to establish Low seasonal yield

Table 3–1, *Characteristics of Perennial Forage Species Grown in Ontario*, opposite page, summarizes the characteristics of each perennial forage species grown in Ontario.

Annual Forages

The main annual crop used to provide forage is corn, which is harvested as corn silage. See *Selecting Hybrids for Silage*, on page 11.

There are several options for annual forage crops. They can be part of a planned cropping program or an emergency remedy to provide feed when perennial forage crops are winterkilled or in short supply. Annual forages are a valuable source of hay, pasture, silage or green feed.

Winter Cereals (Rye, Triticale, Wheat)

Fall rye, winter triticale and winter wheat can provide fall and early-spring grazing. Adequate nitrogen fertility in the spring will provide good stored feed yields by late May. Feed quality decreases as the crop matures. If seeded between August 15 and 31, fall rye can be available for grazing 7 weeks later. Fall rye will produce a larger volume of spring forage than winter triticale or wheat. Fertilize rye to be spring grazed with 50–80 kg/ha (45–70 lb/acre) of nitrogen just before the rye turns green in the spring. Rye will begin to head out after mid-May if not grazed closely.

Winter triticale seed can be difficult to source. Seed 100–125 kg/ha (90–110 lb/acre) at a similar time to fall wheat. Fertilize early in the spring with 80 kg/ha (70 lb/acre) of nitrogen for spring grazing or stored feed. Winter triticale provides early spring grazing similar to fall rye.

Spring Cereals (Oat, Barley, Triticale)

Spring cereals are very adaptable for forage production as hay, silage or pasture. Oat and barley are used extensively as companion crops for perennial forage seedings and are usually harvested as silage to improve the establishment of the perennial forage seeding.

Seed cereals at any time in the season. Early spring planting promotes maximum yields and production. Nitrogen fertilizer enhances vegetative growth, and therefore 30–50 kg/ha (27–45 lb/acre) of nitrogen are recommended. Cutting or grazing can usually begin 6–8 weeks after seeding. Forage quality drops quickly after heading, so harvesting at the late-boot to early-heading stage will maximize feed value. Yield will increase as plants mature, but feed quality drops dramatically. Silage should be wilted to 50%–65% moisture.

Cereal silages are higher in protein than corn silage but usually lower than good-quality alfalfa haylage. Energy values are lower than corn silage and often comparable to alfalfa haylage.

Oat is preferred over barley for pasturing and hay due to their higher palatability. Mixed grain and spring wheat can also be used for forage.

For more information on spring cereal mixtures, see the OMAFRA Factsheet, *Forage Production From Spring*

Cereals and Cereal-Pea Mixtures, Order No. 98-041, or visit the website at www.ontario.ca/crops.

Cereal-Pea Mixtures

Field peas seeded in mixtures with cereals will enhance feed quality. Pea mixtures can increase protein levels and improve forage digestibility if the peas make up at least 50% (by weight) of the seed mixture. Adding peas will increase seed costs. Forage pea varieties are preferred. Avoid using a semi-leafless pea variety in order to maximize leaf yield. Oat with peas may be used as a companion crop for seeding alfalfa but should be harvested for silage. Cut as the oat is heading out — the peas will be just starting to pod. This growth stage will typically occur around the last week of June.

Mixtures of spring triticale and peas can be grown as a forage crop. Seeding rates and crop management are similar to that for oat and peas. Mixtures of triticale and peas usually have more peas in the harvested forage than mixtures of oat and peas. This tends to increase quality but makes wilting slower and increases the length of time the crop must cure before ensiling.

Forage Soybeans

Soybeans are primarily grown in Ontario for oilseed production. However, soybeans can provide a source of high-quality forage as an annual crop. Whole plant soybeans with good pod formation will have similar protein levels and digestibility to alfalfa. Soybeans can be harvested for silage but are difficult to cure for hay.

Take plant height and branching ability into consideration when selecting the variety. Forage soybean varieties have been developed. A solid-seeded planting with a grain drill at a seeding rate of 80–100 kg/ha (70–90 lb/acre) will provide a productive canopy for forage production. Check herbicide labels for registered use restrictions. Harvest soybean forage just as the lower leaves on the plant are beginning to yellow. In Ontario, this usually coincides with the first week in September. Only one cut per season is harvested.

Warm-Season Annual Grasses

Members of the sorghum, sudangrass and millet families are semi-arid, tropical, warm-season annual grasses. Warm-season annual grasses are often considered in emergency forage situations where alfalfa has winterkilled or when planting has been delayed. They offer advantages over corn silage in that they can be produced with conventional forage seeding and harvesting equipment. They can be used in Ontario for silage (chopped or wrapped large bale), green chop or pasture. Sorghums and sudangrass are not recommended as dry hay because they are difficult to cure. Millet is frequently used as haylage or possibly hay, with good drying conditions.

Do not feed sorghums and sudangrass to horses, as they can cause cystitis, an inflammation of the bladder.

Millets

The name "millet" has been given to numerous grasses with small edible seeds. Most millet types, including Japanese, proso, foxtail, barnyard, Koda, finger and Teff, have short (0.3–1.2 m or 1–4 ft), slim stalks. Pearl millet is the exception, with thicker stalks that are over twice as long (1.5–3 m or 5–10 ft). The millets commonly used for forage in Ontario are pearl millet and Japanese millet. With proper management, millets can produce forage with very good quality.

Millets have a smaller stem than sorghums and slightly higher total digestible nutrients (TDN) and protein levels. Millets may be preferred over some sorghums for pasturing or green chop because they do not contain prussic acid. Millets and sorghums can be easily damaged by grazing and therefore should be strip grazed.

Pearl Millet

Pearl millet grows with a mass of very fine fibrous secondary roots and tillers. It exhibits drought tolerance and prefers a lighter sand or sandy loam. Pearl millet can be planted when there is no risk of frost and when soil temperatures are 12°C or warmer. While the last week of May or early June is typically the best time to seed, planting can be delayed until the first of July. The recommended seeding rate is 8–10 kg/ha (7–9 lb/acre) at a 0.5–1 cm (¼–½ in.) planting depth. Growth habits and yields of forage pearl millets are similar to those of sorghum-sudan hybrids.

Quality and quantity of forage produced will be determined by the stage of maturity when harvested. For high feed quality, first-cut is usually ready about 55–60 days after planting, when it is still vegetative. Second-cut is ready about 30–35 days later. Leaving at least 10 cm (4 in.) of stubble results in faster regrowth. When grazing, about 15–20 cm (6–8 in.) of stubble should be left for faster regrowth.

To achieve high yields and protein levels, forage pearl millet will require more nitrogen than the older millet types, but optimum rates have not been determined. The general nitrogen recommendation is likely similar to sorghum-sudan hybrids, split half at planting and half following first cut if a second cut is to be harvested. This split application of nitrogen will optimize yield and quality. There are limited weed control options for pearl millet. Using a stale seedbed practice will improve establishment. For more information on weed control, see OMAFRA Publication 75, *Guide to Weed Control.*

Sorghum Family

Members of the sorghum family used for forage include forage sorghums, sudangrass and various hybrids. There is considerable variability in agronomic and nutritional quality traits among species, hybrids and varieties.

Sorghum and Sorghum-Sudangrass

Forage sorghum and sorghum-sudangrass grow tall and have the potential for high yields. Older forage sorghum varieties were adapted to a high-yield, lower forage-quality, single-cut harvest. Grain sorghums, also called milo, are not recommended for forage production due to low dry-matter yields.

Newer forage sorghum hybrids have been developed to be grown as a short season, two-cut, high-quality forage. Hybrid forage sorghums have fine fibrous secondary roots and tillers, giving them better drought tolerance. Forage sorghums will tolerate heavier soils better than pearl millet. Optimum growth of these plants occurs under hot, moist conditions.

Planting forage sorghums should occur after the risk of frost has past and soil temperatures are above 12°C, typically the last week of May or early June. Seeding rates range from 10–30 kg/ha (9–27 lb/acre). Lower rates can be used under ideal planting conditions and in wider row widths. Generally, higher seeding rates should be used in narrow row widths and under poorer seeding conditions Seed dealers can recommend the seeding rate for the specific variety. Planting depth should be 0.5–1 cm (¼–½ in.). Fertilize with phosphorus and potash according to soil test. The nitrogen recommendation is 50–100 kg/ha (45–90 lb/acre). A split application of nitrogen, half at seeding and half after the first cut, will optimize yield and quality. For weed control, see OMAFRA Publication 75, *Guide to Weed Control.*

The stage of maturity is the most important factor influencing the quality and quantity of forage produced. Typically, forage sorghums are ready for harvesting 60–65 days after planting (late July or early August) and a second cut will be ready 30–35 days later. For faster regrowth, leave at least 10 cm (4 in.) of stubble when cutting, or 15–20 cm (6–8 in.) when grazing. A one-cut silage system will greatly improve yields but at the expense of feed quality. Feed quality drops dramatically after heading. The crop should be wilted and ensiled at about 65% moisture content.

Forage sorghum and sorghum-sudan varieties with brown midrib (BMR) characteristics have been developed with significantly increased fibre digestibility (NDFd). BMR is a genetic mutation that reduces the amount of lignin in the stalk but can also increase the potential for lodging.

Sudangrass

Sudangrass is used for pasturing. It has pencil-size stems and is palatable even after it heads out. Grazing should be delayed until the crop reaches 45 cm (18 in.). Under rotational grazing, the crop will remain productive and succulent throughout the season. Sudangrass can tolerate slightly wetter soils than the other sorghums but does best on medium- to well-drained soils.

Prussic Acid Poisoning

Prussic acid (hydrogen cyanide) poisoning of livestock is a possible concern if feeding sorghums and sudan grass. Young or immature plants, plants suffering from drought stress or plants that have been exposed to frost can contain a higher level of prussic acid. High-nitrogen fertilizer also increases the potential toxicity. Some newer hybrid forage sorghums may have lower levels of prussic acid. Prussic acid poisoning is not a concern with millets. To reduce the risk of prussic acid poisoning:

- Do not graze pastures or green chop stands less than 45–60 cm (18–24 in.) tall.
- Do not green chop or ensile sorghum over 76 cm (30 in.) tall for 3 days after a killing frost.
- Do not green chop plants under 45 cm (18 in.) tall for 3 weeks after a killing frost.
- After a drought, do not graze animals on new growth following a rain.
- Use varieties with reduced prussic acid content.

Nitrate Poisoning

Abnormally high nitrate levels in forages can lead to nitrate poisoning and even death in livestock, and formation of silo gas if the crop is ensiled. Of the various forages, sudan-sorghum and cereals can accumulate the highest levels, forage grasses accumulate intermediate levels, while legumes accumulate levels low enough to rarely be considered a problem. Nitrate poisoning can also be a concern with green chop corn and corn silage.

Nitrate levels are only a problem under abnormal growing conditions, such as:

- very high soil levels of nitrogen (i.e., excessive rates of nitrogen fertilizer or manure or combinations of these along with legume plowdown)
- a long drought, followed by rain. In this situation, delay harvest for 10 days after rainfall, to allow conversion of nitrates to protein.

- any condition that kills the leaves, while roots and stems remain active and accumulate nitrates (such as frost, hail and sometimes drought)

Suspect feeds can be tested for nitrate levels. Ensiling will reduce the nitrate level in the forage. Note that when high nitrate forage is ensiled, deadly nitrogen dioxide gas can be produced (see *Silo Gas*, on page 77).

Forage Brassicas: Forage Rape, Kale and Stubble Turnips

Forage rape, kale and stubble turnips are excellent crops for providing high-quality pasture from September to December. See Table 8–10, *Characteristics of Cover Crops Grown in Ontario*, on page 148, or OMAFRA Publication 19, *Pasture Production*, for more information.

Annual Ryegrass

Annual ryegrass is a rapidly growing bunchgrass that is adapted to a wide range of soil conditions. It regrows continuously throughout the season and has the potential to be highly productive, with enough rain and nitrogen. It is a useful species for mid- to late-season production but does poorly under high-temperature conditions. During periods of little or no rainfall, the plants stop growing and may die.

Two types of ryegrass (with differing growth habits) are available.

Italian Ryegrasses

The Italian ryegrasses are short-lived perennials or biennials, but under Ontario winter conditions behave like an annual. The Italian ryegrasses remain vegetative without a seed-head, producing a lush, leafy growth with high forage quality. They do not usually grow taller than 40 cm (16 in.) and are difficult to harvest as dry hay.

Westerwold Ryegrasses

The Westerwold type is a true annual and grows to 40–80 cm (16–32 in.) high, making it suitable for pastures or hay crops. The Westerwold varieties grow taller, produce stems and are therefore easier to harvest for hay. They should be cut before or just at the heading stage since feed quality decreases rapidly after heading.

Seeding should occur in early spring at a rate of 20–25 kg/ha (18–22 lb/acre) using a drill or cultipacker-type seeder. The seed should be placed 1 cm (½ in.) deep and the seedbed rolled to enhance seed-soil contact to promote good emergence from the light, fluffy seed.

Table 3–2, *Characteristics of Annual Forage Crops in Ontario*, opposite page, summarizes the characteristics of annual forage crops grown in Ontario.

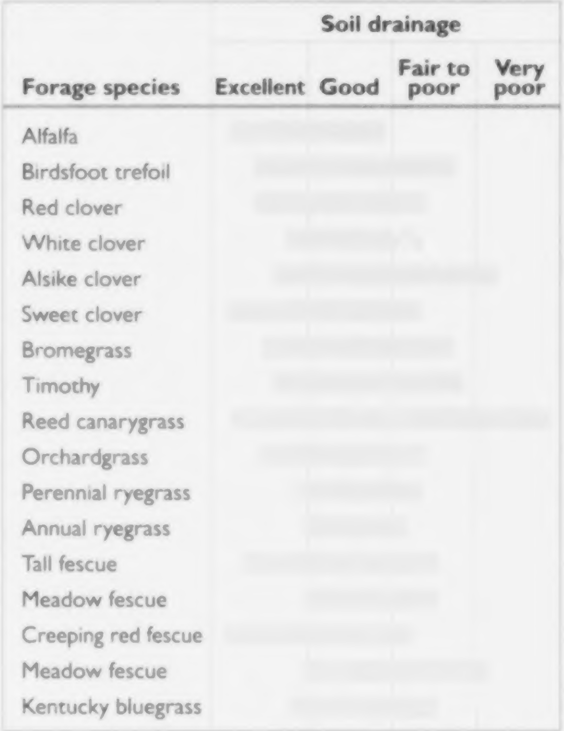


Figure 3–1. Soil Drainage Requirements of Forage Species

Species Selection

Soil conditions often determine which species are suitable in a mixture. Select the legumes first, followed by the grasses, because legumes are often more sensitive to drainage and pH. Soil conditions such as slope or stoniness may make it desirable to seed a legume that has long-term persistence. See *Perennial Legumes*, on page 51, and Figure 3–1, *Soil Drainage Requirements of Forage Species*, this page, for more information on legume tolerance to various soil conditions.

Legumes are usually grown in a mixture with one or more grasses. The major advantages of a pure legume stand are that the protein and energy levels of the feed will likely be greater, quality will decline more slowly with advancing maturity, and quality will vary little from cut to cut. Unless well managed, pure legume stands can have these disadvantages:

- weedier stands
- complete loss of feed supply if winterkill is severe
- slower drying in the windrow
- more lodging
- under some conditions, less palatable feed

Table 3–2. Characteristics of Annual Forage Crops in Ontario

Annual Crop	Use	Seeding Date	Seeding Rate kg/ha	N Rate kg/ha	Avg. Yield TDM/ha	Harvest Maturity
Oat	Pasture Green chop Hay Silage	April–August	80–100	30–50	2.5–4.5 5.5–8.5	Late boot to early head Heads emerged to soft dough
Barley	Green chop Silage	April–June	100–125	40–70	2.5–5.5 5.5–9.5	Late boot to early head Heads emerged to soft dough
Oat + peas or Triticale + peas	Silage	April–June	Oat or triticale: 80–100 peas: 50–75	20–30	2.5–5.0 6.0–9.0	Late boot to early head Heads emerged to soft dough
Fall rye	Pasture	August 15–31	150	50–80 in spring	1.0–1.5	Graze 7 weeks after seeding or early spring
Winter triticale	Pasture	August 25–September 10	100–125	80 in spring	1.0–1.25	Graze 7 weeks after seeding or early spring
Soybeans	Silage	May 20–June 10	80–100	None	6.0–9.0	Lower leaf turns yellow
Annual alfalfa	Hay Silage	Late April	13	None	6.0–12.0	Late bud stage, 5–6 weeks after a cut
Sudan grass	Pasture	June 1–15	15–20	30–50	5.0–7.0	45 cm in height
Sorgum-sudan hybrids	Pasture Green chop Silage	June 1–15	15–20	50–100	8.0–12.0	Boot or early heading
Forage sorghums	Silage Pasture Green chop	June 1–15	14–15 (single-cut, wide-row system 10–30 (multiple-cut, narrow-row system)	100	7.0–9.0	Boot or early heading
Millet	Silage Pasture Green chop Hay	June 1–15	14–20	35–55	4.0–6.0	Boot or early heading
Pearl millet	Silage Pasture Green chop Hay	June 1–15	9–20		4.0–12.0	Boot or early heading
Forage rape	Pasture Green chop	July 1–15	2–6	45–70	7.0–9.0	10–12 weeks after seeding
Kale	Pasture Green chop	June–July	2–6	45–70	9.0–12.0	10–15 weeks after seeding
Stubble turnips	Pasture	July 1–15	2–6	80–100	6.0–9.0	10–12 weeks after seeding
Annual ryegrass	Pasture Green chop Hay Silage	April–May	20–30	Use rates from Table 3–6 on page 66	8.0–12.0	Graze or cut 6–8 weeks after seeding

100 kg/ha = 90 lb/acre
1 t/ha = 0.45 ton/acre

Choosing Species Mixtures

Grass Maturity at Harvest

When selecting the grass, a major consideration should be the maturity of the grass. When using early heading species such as orchardgrass and reed canarygrass, harvesting must be early, or quality and palatability suffer. If harvesting will be later, a later-maturing grass such as timothy is more suitable. Since there is a range in maturity among different varieties within many species, consider variety maturity as well.

Desired Grass-to-Legume Ratio

Consider the ratio of grass to legume desired in the mixture. When a lower protein level is acceptable, such as for beef cow or calf forage, use a higher grass seeding rate for more grass. Higher grass rates tend to reduce weed invasions, particularly by dandelions. If conditions for legume survival are marginal, use higher grass rates for stand insurance. More aggressive grasses, such as orchardgrass, will give more grass in the mixture than less aggressive species, even when similar seeding rates are used.

How Many Cuts Are Planned

Timothy does not crowd alfalfa and under a three-cut system often declines in the stand and provides very little forage in second or third cuts. Orchardgrass provides more midsummer grass in alfalfa mixtures than timothy. If a strong grass component is desired in the harvested forage, particularly in second and third cuts, then use orchardgrass, an aggressive grass that will crowd alfalfa as the stand gets older. Bromegrass and reed canarygrass are intermediate in aggressiveness between timothy and orchardgrass.

Early or Later Harvest

Management can affect the competitiveness of grasses with legumes. Late harvest, when grasses are in bloom, favours the grasses relative to the legumes. This is particularly true with reed canarygrass. Cut at the boot-stage, reed canarygrass does not crowd legumes. If reed canarygrass is allowed to fully head, it rapidly takes over the stand. This is particularly important in birdsfoot trefoil and bromegrass or reed canarygrass mixtures, so harvest promptly at the grasses' boot-stage. If this is not possible or practical, then timothy is a more suitable grass.

Pure Grass Stand

Grasses are not usually grown in pure stands because they are low yielding without heavy applications of nitrogen (see *Fertility Management*, on page 66). Even with adequate fertility, some grass species produce low yields under hot, dry midsummer conditions. However, if soil conditions such as poor drainage make mixtures with legumes impractical, pure grass stands can be very productive with proper fertility programs and species selection. Pure grass stands may be more productive than grass-legume mixtures in some areas of Northern Ontario.

For stored feed, usually only one grass species is recommended. When two or three different species are used together, cutting at the proper stage of maturity for all grasses may be impossible. Timothy is often included with slow-establishing grasses such as bromegrass and reed canarygrass.

Variety Selection

Forage varieties are evaluated each year in tests conducted at a number of locations across Ontario. The results are published in the brochure, *Ontario Forage Crop Variety Performance*, available at OMAFRA Resource Centres or on the Ontario Forage Crops Committee website at www.uoguelph.ca/plant/performance_recommendations/ofcc/ofcc.htm. This brochure provides information on the yield performance of recommended varieties relative to reference varieties. Information is also provided on other factors, including persistence, disease and insect resistance, maturity and regrowth rate.

Table 3–3, *Recommended Forage Mixtures for Stored Feed and Pasture*, opposite page, summarizes the characteristics of the perennial forage species and mixtures grown in Ontario.

All forage seed sold under a variety name must be labelled "certified seed" and have a blue tag verifying it, which ensures that it is the named variety. Certified seed must meet specific requirements for germination and weed seed content.

Forage seed may also be sold as common seed or as a brand. Common seed and brands may be blends of different seed lots. They must also meet requirements for germination and weed seed content, although the standards are less rigorous than for certified seed. No assurance of characteristics such as disease resistance or hardiness is possible for common seed. Therefore, the performance of stands established using common seed or brands is unpredictable and will often vary from year to year. The use of certified seed, rather than brands or common seed, is strongly recommended. Only by planting certified varieties is it possible to know in advance whether the seed you plant will provide yield, persistence, disease resistance and maturity.

Table 3–3. Recommended Forage Mixtures for Stored Feed and Pasture

Components	Seeding Rate[1] kg/ha	Recommended for			Specific Recommendations
		Stored Feed	Managed Pasture	Intensively Pastured	
1. Alfalfa	13	X			Only on well-drained fields. Easier to cure as silage than as hay. Harvest at bud stage for high nutrient-quality feed.
2. Alfalfa Timothy	13 1	X			Increase timothy up to 4 kg/ha for higher grass content and easier curing. Timothy gives stand insurance in areas prone to alfalfa winterkill. For high nutrient quality feed, harvest timothy at boot stage. On severely dry soils or in areas with over 3,100 CHUs, bromegrass is preferable to timothy.
3. Alfalfa Bromegrass	11 9	X			Will give somewhat better midsummer production than timothy mixture. Retains quality with increasing maturity better than orchardgrass or timothy mixtures. Bromegrass can thicken stand over time because of its rhizomes.
4. Alfalfa Orchardgrass	11 2	X		X	Select late orchardgrass and early alfalfa varieties. Graze or cut early to maintain quality and palatability. Percentage grass will be higher in all cuts than with timothy or bromegrass mixtures.
5. Alfalfa Orchardgrass White clover	9 2 2	X		X	Same as 4. High fertility and good grazing management needed for top production. Alfalfa included as insurance against severe dry conditions but requires longer regrowth intervals to persist.
6. Alfalfa Timothy Bromegrass White clover	9 4 9 2	X		X	Suitable for hay/pasture combinations.
7. Birdsfoot trefoil Timothy	9 2	X	X		Use later-maturing timothy varieties.
8. Birdsfoot trefoil Bromegrass	9 4	X	X		For long-term stands and early production. Graze early to reduce competition from bromegrass. Good brome growth in fall.
9. Birdsfoot trefoil Orchardgrass	8 4			X	Good early and mid-season production. Graze down orchardgrass to reduce competition with birdsfoot trefoil. Later-maturing orchardgrass varieties are preferred.
10. Birdsfoot trefoil Tall fescue[2]	8 10	X	X	X	Good production throughout the season. Good tall fescue growth and quality in the fall.
11. Birdsfoot trefoil Creeping red fescue	8 6		X		Good summer and fall production. Excellent quality in fall.
12. Red clover	11	X			Short-term haylage production or plowdown crop.
13. Red clover Timothy	7 6	X			Short-term haylage production. When clover disappears, plow or fertilize with nitrogen to maintain production.
14. White clover Orchardgrass	2 9			X	For pasture use where white clover is adapted. High fertility, adequate moisture and good grazing management required for top production. In dry areas, add alfalfa (see 5 above).

1 kg/ha = 0.9 lb/acre

[1] For early seeding on a fine, firm seedbed, these rates may be reduced by 25% except where coated seed is being used.

[2] Use endophyte-free seed.

Tillage

Seedbed Preparation

The goal of tillage is threefold:

- to produce a firm, level seedbed that allows good control of seeding depth
- to produce a fine seedbed that permits good soil to seed contact
- to produce a smooth surface for the harvesting operations

Forage seed is very small, making good seed-to-soil contact essential for germination, particularly in dry conditions. A loose, lumpy seedbed dries out quickly, and lumps make the emergence of young seedlings difficult. Soil should be firm enough at planting for a footprint to sink no deeper than 9 mm (⅜ in.). Packing before seeding can help, especially on sandy loam soils, which often produce a "fluffy" seedbed. Pack as soon as possible after seeding to prevent excessive moisture loss. On clay loam soils, forage establishment is most reliable when the field has been fall plowed. Freezing and thawing action on these soils result in easier preparation of a fine seedbed the following spring.

Heavier soils plowed in the spring often require excessive tillage to produce a fine seedbed. If soils are worked too fine, a surface crust can occur after a heavy rainfall, reducing emergence, increasing erosion potential and decreasing water infiltration.

No-till seeding of forages has been quite successful where the soil conditions following the previous crop were smooth and level. Weed control and proper seed placement are important. Where surface residue is heavy, slug damage to forage seedlings is a risk.

Land susceptible to erosion will benefit from increased surface residue. However, seeding equipment must be able to handle the increased residue left by reduced tillage systems without compromising seed placement and adequate seed-soil contact.

Establishment (Planting)

When selecting a field, consider whether it is suitable for the mixture you wish to plant. Limitations such as low pH, poor drainage or weed problems such as quackgrass, should be corrected prior to seeding.

Seeding Time

Spring Seeding

The most reliable time to seed forages is early spring, regardless of whether the crop is direct-seeded or seeded with a companion crop. With a spring seeding, moisture is usually adequate, and the plants are well established for winter survival. Seed as early as a seedbed can be prepared to increase the chances of adequate and frequent rainfall during the critical germination period.

Summer Seeding

Summer seeding can be a viable alternative to spring seeding. A summer seeding can typically follow winter or spring cereal harvest. Companion crops are not recommended in summer seedings because they compete too strongly for available soil moisture. Summer seedings can work well on lighter soils but present a higher risk on heavier soils.

Seeding Date

Seeding too early in the summer increases the risk of hot, dry conditions affecting germination and seedling development. Seeding too late increases the chance of receiving a killing frost before legume seedlings are adequately established and accumulate enough root reserves to survive the winter. Legumes seeded in September or October rarely survive the winter since small legume plants are more susceptible to heaving. Even if these plants survive, they will be slower starting and lower yielding. Alfalfa requires approximately 6 weeks of growth after germination to survive the winter. Alfalfa will generally survive if the crown develops before a killing frost.

Summer-seed before the following dates:

- more than 3,100 CHUs — August 10–20
- 2,700 to 3,100 CHUs — August 1–10
- less than 2,700 CHUs — July 20–30

Birdsfoot trefoil has slow seedling development, so summer seedings are usually unsuccessful. September seeding of straight grasses may be successful, with the exception of reed canarygrass, which is slow to establish.

Seedbed Preparation

Seed to soil contact is particularly important in dry summer conditions. A loose, lumpy seedbed dries out quickly. Packing can help preserve moisture. A fine seedbed can be more difficult to prepare in August on clay loam soils, compared to loams, sandy loams and silt loams.

Heaving

Avoid summer seeding on heavier soils that have a history of alfalfa heaving.

Weed Control

Winter annual weeds can be a common problem, and herbicide application may be required. See OMAFRA Publication 75, *Guide to Weed Control*. Be cautious to avoid delaying growth due to a herbicide effect.

Table 3–4. Recommended Seeding Rates for Legume and Pure Grass Stands and Approximate Seeds/Weight of Various Forage Species

Species	Seeding Rate		Seeds/kg	Seeds/lb
	kg/ha	lb/acre		
Legume Species				
Alfalfa	13	11.5	440,000	200,000
Red Clover	11	10	605,000	274,000
White Clover	—	—	1,760,000	798,000
Birdsfoot trefoil	9	8	935,000	424,000
Sweet clover	8–10	7–9	572,000	259,000
Alsike	—	—	1,540,000	699,000
Pure Grass Species[1]				
Timothy	8–10	7–9	2,706,000	1,227,000
Orchardgrass	8–10	7–9	1,439,000	653,000
Bromegrass	10–14	9–12.5	300,000	136,000
Meadow & tall fescue	9–11	8–10	506,000	230,000
Meadow fescue[2]	10–12	9–11	506,000	230,000
Perennial ryegrass	10–15	9–13.5	500,000	227,000
Reed canarygrass	10–12	9–13.5	1,173,000	532,000
Bluegrass	—	—	4,790,000	2,173,000

[1] For early seeding on a fine, firm seedbed, these rates may be reduced by 25%, except where coated seed is being used.

[2] Use coated seed. Seed through the grain seed box.

Volunteer Grain

Volunteer grain, because it may be thick and competitive, can be a serious problem in summer seedings. Oat or barley will winterkill in November, but winter wheat will be present until the first cut the following year. Tillage can be used to reduce the problem of volunteer cereals. There are herbicides that will kill volunteer cereals, but forage grasses in the mixture will be stressed or may also be killed.

No-Till

No-till summer seeding can be successful if proper attention is paid to residue management, seed placement and weed control. However, using no-till to reseed an existing alfalfa field in August is not recommended due to alfalfa autotoxicity (see *Alfalfa Autotoxicity*, on page 65), slugs and disease that may exist in the old sod.

Seeding Rates and Depth

The amount of seed recommended in Table 3–3, *Recommended Forage Mixtures for Stored Feed and Pasture*, on page 61, and Table 3–4, *Recommended Seeding Rates for Legume and Pure Grass Stands and Approximate Seeds/Weight of Various Forage Species*, this page, is intended for average to good conditions. Under excellent management and favourable conditions for establishment, these rates may be reduced by 25%. When coated seed is used, do not reduce these rates, because coated seed contains fewer seeds per unit weight. Do not expect very high seeding rates to compensate for poor conditions (a rough seedbed, heavy companion crop, etc.).

Seed size can vary between varieties and between seed lots of the same variety. Seeder calibration can help avoid over- or under-seeding. See Table 3–4, above.

> As a rule of thumb, seeding depth for most forages should be 6–12 mm (¼–½ in.) on clay and loam soils, and 12–18 mm (½–¾ in.) on sandy soils.

Emergence declines rapidly if forage seeds are planted more than 20 mm (¾ in.) deep. Legume seed on the soil surface may establish if moisture conditions following seeding are ideal. Success of surface seeding is much greater with late-March-to-early-April seedings (including frost seeding) than in late-April or May.

Seeding Equipment

Grain Drill

The grain drill with a grass seed attachment is the most common method of seeding forages. The standard grass seed box will handle legume seeds and smaller grass seeds such as timothy and reed canarygrass. Some drills have an additional seed box designed to seed coarser grasses, such as bromegrass and orchardgrass, which do not flow well through the standard box.

Most drills have drop pipes attached to the grass seed box. Where fertilizer is applied through the grain drill, align the drop pipes so that seed is dropped in a row over the fertilizer placed by the disc opener. Drop the seed 25–35 cm (10–14 in.) behind the disc opener to allow some soil to cover the fertilizer band before the seed is dropped. This placement also ensures that the seed is not planted too deep.

Packing the soil after planting can result in more even germination, particularly during dry springs. Press wheels help cover the forage seeds and firm the soil around the seed.

If press wheels are not available, a packer or rubber tire roller pulled behind the drill to firm the soil have given satisfactory results. A packer is not recommended if the soil is wet, particularly on clay loam soils, where crusting can be a problem.

Packer Seeders

Packer seeders, such as Brillion seeders, can be used successfully to seed forages. They are equipped with both fine and coarse seed boxes. The first roller firms, levels and grooves the soil; the seed is then dropped on this surface. The second roller covers the seed with soil and firms it around the seed. This type of seeder does an excellent job of controlling seed depth and firming the seedbed. It does not apply fertilizer and thus does not produce the starter effect achieved with the grain drill-band seeding method. This is a disadvantage mainly at low and medium soil phosphorus fertility levels.

Broadcast Seeders

Broadcast seeders are also used for forages. Their main advantage is increasing the speed of seeding. Control of seeding depth is a problem and packing is necessary to cover the seed.

There are two types of broadcast seeders:

- Seeders that use spinners can give uneven distribution, particularly under windy conditions or with seed mixtures containing light and heavy seeds. This seeding method usually results in inferior stands and is not recommended.
- Air-flow boom seeders overcome the problems of wind and seed segregation while still permitting very rapid seeding.

No-Till Drills

This seeding system for forages can work well, but there have been failures. To avoid stand failures, consider these guidelines:

- Ensure residue, including chaff, is evenly distributed.
- Eliminate perennial weeds, including quackgrass, before seeding. Control annual weeds in new seedings.
- Plant no deeper than 18 mm (¾ in.) on lighter soils or 12 mm (½ in.) on clay loam soils. Check that openers are placing seed into the soil, rather than into surface residue.
- No-till spring seedings into soybean, cereal and corn residues for the most reliable results. Remove straw from the previous crop to improve seed placement.
- Kill the sod in the fall for fields where legumes will be no-till spring-seeded. Avoid top growth of more than 15 cm (6 in.) at spraying time to reduce the risk of insects, disease and alfalfa autotoxicity (see *Alfalfa Autotoxicity*, opposite page).

Seeding With a Companion Crop

Much of the forage acreage in Ontario is seeded under a companion grain crop that suppresses annual grass weeds and gives fairly rapid protection from erosion on rolling land. The disadvantage of a companion crop is that it competes with the forages for moisture, light and fertility. If any of these items are deficient, the forage seeding will suffer before the grain crop does.

Harvesting the Companion Crop as Grain

This system of seeding provides a grain crop and a crop of straw while the forage crop is being established. Competition from the grain crop reduces forage establishment and subsequent yields, so it is generally not recommended. Lodging of the companion crop or delayed baling of straw can be risks to forage establishment. The primary purpose of the seeding is to establish the forage, while grain and straw production are of secondary importance.

Recommended Guidelines

- Oat, barley or mixed grains are commonly used as companion crops. Spring wheat or spring triticale can also be used as a companion crop and generally provide less competition to the forage seeding. Six-row barley is preferable to two-row barley.
- As a general rule, select the strongest-strawed, shortest and earliest grain variety in any species for the least competition.
- Reduce the spring grain seeding rate to 60–70 kg/ha.
- Reduce the nitrogen fertilizer or manure rate to minimize the risk of a dense grain crop and lodging. Under most conditions, do not apply more than 15 kg/ha of nitrogen on spring grains.

Harvesting the Companion Crop as Silage

Harvesting the grain crop as silage can eliminate some of the problems associated with seeding forages under grain while still allowing weed suppression and erosion control. The companion crop is removed before it lodges or competes excessively for light and moisture.

Match the stage of cereal at cutting to the livestock nutritional requirements. For high feed quality, cereals should be harvested at the late-boot stage. Delaying harvest to the fully headed stage will increase yield but reduce forage quality. The seeding rate of the cereals and the nitrogen application may be the normal rates in order to increase the silage yield. With reasonable soil moisture following harvest, it is quite possible to also obtain a cut of forage in late August in areas with 2,800 crop heat units or more.

Direct Seeding

Seeding forages without a companion crop removes the potential threat to establishment from the grain crop. Under good management, direct-seeded forage stands are often thicker and more uniform. This is particularly true of forage species such as birdsfoot trefoil, alfalfa and reed canarygrass, which do not tolerate heavy shade. Since a grain crop is not competing for soil moisture, direct seedings are less affected by June or July droughts.

Early-spring direct seedings can be expected to give one or two cuts of forage in the seeding year, yielding 50%–60% of an established stand. Direct-seeded forages are useful when the harvested forage acreage must be increased on short notice to compensate for winterkill or increased forage requirements.

Direct seedings have been most popular in Ontario:

- on silt loam, loam and sandy loam soils
- with birdsfoot trefoil- or alfalfa-based mixtures
- on dairy farms where nitrogen build-up from livestock manure frequently results in cereal grain lodging
- where other crops provide the grain and straw requirements

Direct seedings have not met with success on all farms. Weed competition is a greater problem with direct seeding than with under-seeding. See Chapter 12, *Weed Control*.

In the year of seeding, the root systems of forage crops are shallow and more vulnerable to dry weather than established stands. Moisture stress can reduce production to one cut rather than two but do not usually reduce the stand.

Direct seedings on heavier clay loam soils require more skillful seedbed preparation and seeding. Clay soils, particularly where the seedbed is somewhat lumpy, are more vulnerable to dry conditions during germination, thereby reducing establishment. They also are more vulnerable to crusting and seedling emergence problems if heavy rains follow seeding.

Alfalfa Autotoxicity

Seeding alfalfa after alfalfa is high risk because old stands of alfalfa release a toxin that reduces germination, root development and growth of new alfalfa seedlings. This is called autotoxicity. Roots are swollen, curled, discoloured and lack root hairs. The negative effects on root growth can significantly impact yields for the life of the stand.

Reseeding alfalfa within 2–3 weeks of killing an old alfalfa stand will result in reduced germination and thin stands. A longer delay will allow full stand establishment, but because the toxins are present for up to 6 months, the plants can suffer damage below ground that will limit yields for the life of the stand. For maximum yields, if the alfalfa is 2 or more years old, an intervening year of an alternate crop is required before reseeding to alfalfa.

The toxins are not present the first year in new seedings, so seeding failures or new seeds that were winterkilled can be reseeded without an autotoxicity effect. This would include a summer seeding after an unsuccessful spring seeding, or a spring seeding after an unsuccessful summer seeding.

It is not recommended that interseeding be done to thicken an established alfalfa stand, as this is rarely successful. New seedlings often germinate, look acceptable early and then die out over the summer. Thin spots can sometimes be interseeded with red clover instead.

Inoculation

For normal growth, all legumes must have nitrogen-producing nodules on their root systems. These nodules are produced by *Rhizobium* bacteria.

Legume species (alfalfa, clover, birdsfoot trefoil) require their own specific strain of *Rhizobium* for proper nodulation. If a legume is being planted for the first time in a field, the seed must be inoculated with the proper strain of *Rhizobium* bacteria before planting. Pre-inoculated seed is satisfactory, provided that the inoculant is applied in the current season. Since the inoculant must be alive, note the expiry date and handling precautions on the packet to ensure effective nitrogen fixation. When a forage legume species has routinely been grown in a field as part of the rotation, these bacteria are usually present in the soil and should result in good nodulation. The cost

Table 3–5. General Nitrogen Recommendations – Perennial Forages

Crops	Nitrogen Required kg/ha
Legume or legume-grass at seeding	
Without a nurse crop	0
With a nurse crop	15
Unimproved pasture	50
Grass for seed	90
Hay or pasture	
Half or more legumes	0
One-third-to-half legumes	60
Grass (less than one-third legumes)	(See Table 3–6)
100 kg/ha = 90 lb/acre	

of the *Rhizobia* is low in comparison to the cost of seed. If there is any doubt about the presence of *Rhizobia* in the soil, the seed should be inoculated.

Fertility Management

Nitrogen

Forage stands that are more than 50% legume do not require nitrogen fertilizers. For nitrogen recommendations, see Table 3–5, *General Nitrogen Recommendations – Perennial Forages*, this page, and Table 3–6, *Nitrogen Recommendations for Improved Grass Hay or Pasture*, this page.

Grass stands containing less than one-third legumes require large amounts of nitrogen to optimize yield. Where conditions permit, it is generally more profitable to reseed to mixtures containing legumes. It can be profitable to fertilize grass stands consisting of productive species such as bromegrass, orchardgrass or timothy. The use of nitrogen will also increase the protein level in the grass. The rates of nitrogen recommended for grass stands have been developed on the basis of the price of nitrogen relative to the value of hay (see Table 3–6, this page). Make the first application for hay or pasture as early as possible in the spring, followed by a second application after the first cut and a third application after the second cut. To avoid the danger of nitrate toxicity, apply no more than 170 kg/ha (150 lb/acre) of nitrogen at any one time.

Nitrogen deficiency in forages shows up as a general yellowing and stunting of the plants. It may show in the lower parts of the plants first. In legumes, a nitrogen deficiency usually indicates poor nodulation and/or low soil pH.

Table 3–6. Nitrogen Recommendations for Improved Grass Hay or Pasture

Application No.[1]	Nitrogen:Hay Price Ratio				
	10	**15**	**20**	**25**	**30**
	N required[2] (kg/ha)				
1	140	120	100	80	70
2	110	90	70	50	30
3	90	75	60	45	30
100 kg/ha = 90 lb/acre					

[1] Make first application before May 10 and second application after the first cut. Make a third application after the second cut only if there is reasonable assurance of a third cut.

[2] For stored feed: Where manure is applied, reduce the fertilizer application according to the type and amount of manure (see *Manure*, on page 69). For pasture: Reduce all rates by one-third because of recycling through manure and urine.

Nitrogen/Hay Price Ratio

The most profitable rate of nitrogen application is also affected by the relative prices of hay and nitrogen, which can be expressed as a nitrogen/hay price ratio. This ratio is calculated by dividing the cost of nitrogen, in dollars per kilogram of actual N, by the value of the hay, in dollars per kilogram.

a) To determine the cost per kg of actual nitrogen, divide the cost per tonne of fertilizer material by 10 times the percentage of nitrogen in the fertilizer. Include application costs.

$$\text{Cost of N/kg} = \frac{\text{Cost of nitrogen fertilizer per tonne}}{10 \times (\text{\% Nitrogen in fertilizer})}$$

b) To determine the value per kg of hay, divide the value per tonne by 1,000. The value of the hay may be the anticipated selling price, or it may be the cost to replace that hay with other feeds in the ration.

c) To determine the nitrogen:hay price ratio, divide the cost of N per kg by the value of the hay per kg.

$$\text{Nitrogen/hay price ratio} = \frac{\text{Cost of N/kg}}{\text{Value of hay/kg}}$$

Table 3–7. Phosphate Recommendations for Forages Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	At Seeding With or Without a Nurse Crop		Band Seeded Without a Nurse Crop[3]		Established Stands		Unimproved Pasture	
	Rating[1]	Phosphate (P_2O_5) Required[2] kg/ha	Rating[1]	Phosphate (P_2O_5) Required[2] kg/ha	Rating[1]	Phosphate (P_2O_5) Required[2] kg/ha	Rating[1]	Phosphate (P_2O_5) Required[2] kg/ha
0–3	HR	130	HR	130	HR	180	HR	70
4–5		110		110		120		60
6–7		90		90		90		50
8–9		70		70		60		30
10–12	MR	50	MR	50	MR	30	MR	20
13–15		30		40		20		20
16–20		20		30	LR	0	LR	0
21–25		20		20		0		0
26–30	LR	0	LR	20	RR	0		0
31–40		0		20		0	RR	0
41–50	RR	0		20		0		0
51–60		0	RR	0		0		0
61+	NR	0	NR	0	NR	0	NR	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR, and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] Where manure is applied, reduce the fertilizer application according to the amount and quality of manure (see *Manure*, on page 69.

[3] For use only where seed is banded directly above the drilled fertilizer.

Phosphate and Potash

Phosphate and potash recommendations are given in Table 3–7, *Phosphate Recommendations for Forages Based on OMAFRA-Accredited Soil Tests*, this page, and Table 3–8, *Potash Requirements for Forages Based on OMAFRA-Accredited Soil Tests*, next page. For information on the use of these tables or if an OMAFRA-accredited soil test is unavailable, see *Fertilizer Recommendations*, on page 158.

When direct-seeding on soils that require phosphate fertilizer, establishment may be improved by the placement of a high phosphate fertilizer 5 cm (2 in.) directly below the seed. Using a grain drill with fertilizer and grass seed attachments, this placement may be accomplished by drilling the fertilizer through the furrow opener and dropping the forage seed on a firm soil surface directly behind the furrow opener. Usually it is advisable to firm the soil surface immediately after seeding.

Potash may be more effective in promoting persistence if it is applied within the 6 weeks before the start of the fall rest period. Potash deficiency is occasionally found in alfalfa, showing symptoms of small, light dots on the leaflets. These dots can be on any part of the leaflet but are usually concentrated near the margins (Plate 20 on page 282). Grasses and clovers are much less likely to show potash deficiency symptoms. Phosphate, if required, may be applied with the potash or at other times of the year. Phosphate deficiency symptoms are rare and non-specific in forages, but a shortage of phosphate may manifest itself as stunting and poor winter survival of legumes.

Plant Analysis

When analyzing forage legumes, sample each species separately. Cut the plant at normal mowing height at the late bud stage. See Table 3–9, *Interpretation of Plant Analysis for Alfalfa*, next page. Plants suspected of nutrient deficiency, however, should be sampled as soon as the problem appears. For sampling at times other than heading, and for species other than alfalfa, samples should be taken from both deficient and healthy areas of the field for comparative purposes. A soil sample should be taken from the same area and at the same time as the plant sample.

Table 3–8. Potash Requirements for Forages Based on OMAFRA-Accredited Soil Tests

Ammonium Acetate Potassium Soil Test (ppm)	At Seeding With or Without Nurse Crop		Fall Applications for New Seeding and Established Stands	
	Rating[1]	Potash (K_2O)[2] Required kg/ha	Rating[1]	Potash (K_2O)[2] Required kg/ha
0–15	HR	90	HR	480
16–30		80		400
31–45		70		320
46–60		50		270
61–80		40		200
81–100	MR	30		130
101–120		20	MR	70
121–150		20		20
151–180	LR	0	LR	0
181–250	RR	0	RR	0
251+	NR[3]	0	NR[3]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR, and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] Where manure is applied, reduce the fertilizer according to the amount and quality of manure (see *Manure*, opposite page).

[3] A rating of "NR" may mean reduced yield or quality of crops primarily due to magnesium deficiency. Natural levels above 251 occur occasionally on clay and clay loam soils but are not expected to cause problems because soils naturally high in potassium are usually also high in magnesium.

Micronutrients

Boron

Boron is important for alfalfa, however, its application is not required on all soils. A deficiency shows up mainly on high-pH, sandy soils. Boron applications are recommended on all sandy soils and, in particular, the sandy loam and loam soils in the area east of the Niagara Escarpment up to and including Frontenac County. Boron deficiency is seen most frequently on droughty soils under dry conditions.

A shortage of available boron to the alfalfa plant first affects flowering and reduces seed-set. As the deficiency becomes more serious, the youngest upper leaves of the plant become yellow to red in different plants (Plate 21 on page 282). Growth can be severely stunted and winter hardiness reduced.

Table 3–9. Interpretation of Plant Analysis for Alfalfa

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	–	5.5
Phosphorus (P)	%	0.20	0.5
Potassium (K)	%	1.70	3.5
Calcium (Ca)	%	–	4.0
Magnesium (Mg)	%	0.20	1.0
Sulphur (S)	%	0.22	–
Boron (B)	ppm	20.0	90.0
Copper (Cu)	ppm	5.0	30.0
Manganese (Mn)	ppm	20.0	100.0
Molybdenum (Mo)	ppm	0.5	5.0
Zinc (Zn)	ppm	10.0	70.0

Values apply to the plant cut at normal mowing height at the late bud stage.

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

Boron deficiency can usually be corrected or prevented by an application of 1.0–2.0 kg/ha of boron broadcast annually. Boron should not be banded at seeding.

Do not apply mixtures of herbicides and fertilizers to crop foliage unless recommended by competent authorities. For further details on boron deficiency and on methods of application, visit the OMAFRA website at www.ontario.ca/crops.

Sulphur

Sulphur deficiency has not been observed on forages in most of Ontario. The sulphur in acid precipitation falling on Northeastern and Southern Ontario is sufficient for crop requirements. There have been scattered reports of sulphur deficiency in alfalfa in Northwestern Ontario on sandy soils with low organic matter. The appearance of sulphur deficiency is similar to nitrogen deficiency with general yellowing of the plants.

Other Micronutrients

Deficiencies of copper, zinc or manganese have not been observed in forages in Ontario.

Manure

Manure is an excellent source of nutrients and can substitute for manufactured fertilizers. It is an excellent source of nitrogen for grasses and, when applied after the first or second cut, can give a forage yield and quality boost. Apply liquid manure as soon as possible after harvest, before re-growth. Application to older grass-alfalfa stands will give the largest benefit. Do not apply manure to perennial forage legumes when there is snow cover, because ice frequently forms under the manure and can kill the plants.

Liming

Legumes generally are not tolerant of acid soil conditions. Acid soils should be limed 1 year before seeding at rates indicated by soil tests. (See *Soil Acidity and Liming*, on page 158.) Applying lime to established stands is not normally profitable.

Harvest and Storage

Pasture Management

A well-managed pasture will provide an abundance of low-cost forage for livestock. To harvest the optimum amount of forage and achieve the best livestock performance, use a rotational system. Ideally, a pasture will contain at least 35% legume in the forage being consumed by the livestock. Soil drainage and texture will influence the choice of forage species. Pastures with less than 35% legume content will benefit from the application of nitrogen at 50–75 kg/ha. Timing should coincide with good growing conditions and the need for more pasture. Use multiple applications if applying more than this rate.

Rotational Grazing

Spring turn-out of livestock should be timed according to the grass growth. Graze early species, such as orchard grass, early or growth will become too mature. Rotate the grazing fairly quickly. The faster the grass is growing, the quicker the rotation should be. With rotational grazing, it is important to gauge moving the livestock based on the last paddock planned for grazing in the rotation. In the early part of the growing season, a compete rotation may take 20 days. Late in the season, it may take 40 or more days for adequate re-growth and recovery before re-entry into a paddock.

Bloat Management on Pasture

Legumes can cause bloat of ruminant livestock. The younger the plants, the greater the risk. When grazing pasture that is greater than 50% legume, there are a number of steps that will reduce the risk of bloat:

- Have the livestock full of forage when they enter the pasture.
- Move livestock when the pasture is dry, not early in the morning with heavy dew or when wet with rain.
- Offer dry stemmy hay to assist rumen stimulation.
- Graze legumes when they're in bloom.
- Consider using a feed additive.
- Offer small areas at a time (equivalent to 1 day) to encourage the livestock to eat the stems as well as the bloat-causing leaves.

For more information on pasture management see OMAFRA Publication 19, *Pasture Production*, available on the website at www.ontario.ca/crops.

Forage Quality

For forages that are harvested for storage, the type of livestock being fed determines the appropriate quality of forage. Match forage quality to the nutritional requirements of the animal. High-producing dairy cattle require quality feed that is high in digestible energy and protein. The benchmark alfalfa analysis for high-producing dairy cows is 20% crude protein (CP), 30% acid detergent fibre (ADF) and 40% neutral detergent fibre (NDF). For a beef cow, the most appropriate hay is more mature and higher yielding, and is therefore lower in protein and digestibility. Many recreational horse owners prefer hay that is more mature and contains more grass than is common in dairy hay. It is very important that it be entirely free of rain damage, mould and dust. Some markets also require hay to be green in appearance and entirely free of weeds. The remainder of this section will use the term "high nutrient quality" to mean high in protein and digestible energy.

Laboratory analyses of forages are essential for accurate ration formulation. The nutrient content of forages varies greatly depending on the type, stage of maturity at cutting and how well it is preserved.

See the OMAFRA Factsheet, *Definition of Feed Manufacturing and Livestock Nutrition Terms*, Order No. 08-039, for help with interpreting forage analyis reports.

Measuring Corn Silage Digestible Energy

Corn silage is unique since it consists of two very different components — high moisture grain and stover. High digestible energy is important to reduce the need for supplemental grain. Lower neutral detergent fibre (NDF) and increased digestible fibre (NDFd) are important for increasing intake, as well as energy.

Table 3–10. Digestibility and Protein of Alfalfa and Bromegrass at Various Stages of Maturity

		% Digestibility		% Crude Protein	
Stage of Maturity	**Date**	**Alfalfa**	**Bromegrass**	**Alfalfa**	**Bromegrass**
Medium bud	June 4	72.6	73.8	21.5	13.4
Early flower (heads emerged)	June 20	65.2	67.2	17.0	10.0
Full flower	June 30	62.1	60.6	16.2	6.7
Early seed	July 6	60.9	59.7	15.6	5.8

Digestible energy of corn silage is primarily determined by the relative amounts of starch and fibre (NDF) and their digestibilities. In the past, acid detergent fibre (ADF) was used to estimate energy, and NDF was used to estimate intake, but these measures alone do not consider digestibility. Newer methods more accurately estimate corn silage digestible energy using crude protein (CP), NDF, NDFd, starch, ash and fat. Starch digestibility can also be estimated using moisture, kernel processing scores and other laboratory starch digestibility tests.

Forage Harvest Timing

The timing of harvest is the most important consideration when trying to produce high-nutrient-quality forage. Forage crops decline in feeding value as they mature. Once alfalfa buds appear, feeding value declines about 0.2% per day in protein and about 0.4% per day in digestibility (see Table 3–10, *Digestibility and Protein of Alfalfa and Bromegrass at Various Stages of Maturity*, this page). Short delays in cutting result in significantly lower forage nutrient quality. Of course, finding a window of dry weather can complicate things even further.

As a general rule of thumb, cut high-nutrient-quality, first-cut forage at the mid-bud to full-bud stage.

The timing of cutting is determined by the nutritional requirements of the livestock being fed. Cutting at the pre-bud or early-bud stage will result in reduced yields and may increase the risk of losing the stand. Extremely low fibre levels may result in nutritional problems. With grasses, a compromise between yield and quality occurs at "early head emergence from the boot." Orchardgrass will mature much earlier than timothy and bromegrass. Delayed harvesting of forage will give higher yields and greater plant persistence, but lower feed quality. With a large acreage of forage, it is advisable to start cutting earlier to ensure the later-cut material will still have adequate quality.

Subsequent second and third cuttings of alfalfa may be at intervals of approximately 30 days (mid-bud) to 40 days (early flower) or more, depending on whether the goal is high quality or maximum persistence and yield (see *Forage Winterkill*, on page 78).

Predicting Alfalfa Quality in a Standing Crop

Methods being used to determine when to begin cutting first-cut alfalfa include:

- the calendar date
- stage of development (mid-bud, full-bud, etc)
- growing degree days (GDDs) (see *Growing Degree Days*, on page 180)
- scissors cut
- Predictive Equations for Alfalfa Quality (PEAQ)

Many producers base cutting decisions using NDF as the primary quality variable. For high-producing dairy cows, optimum alfalfa NDF for intake and dietary fibre is approximately 40%. With warm weather, NDF can increase about 0.7 units per day, and therefore quality can drop rapidly. NDF can vary from one year to the next by up to 10% when cutting is on the same date. The relationship between morphological stage, such as early- or late-bud stage, and NDF is not always high. Some laboratories offer scissor-cut analysis with a rapid turnaround time, in order to monitor forage quality in a standing crop.

The PEAQ method uses the longest stem and the most mature stems to estimate the NDF of the alfalfa in a standing crop. A PEAQ stick incorporates the NDF estimates onto an easy-to-read measuring stick, which can be used in the field. PEAQ is intended for use as a tool in making cutting decisions and is not meant to replace forage analysis and ration balancing. For details on how to use the PEAQ system, see *Predicting Alfalfa Quality Using PEAQ* on the OMAFRA website at www.ontario.ca/crops.

Dry Hay

The greatest amount of feed value is stored when both field and storage losses are minimized. The amount of each loss is largely determined by the moisture content of the forage when going into storage. Storing dry hay results in high field losses but relatively small storage losses. On the other hand, storing forages as haylage gives lower field losses but higher storage losses (see Figure 3–2, *Estimated Hay and Haylage Harvest and Storage Losses*, opposite page).

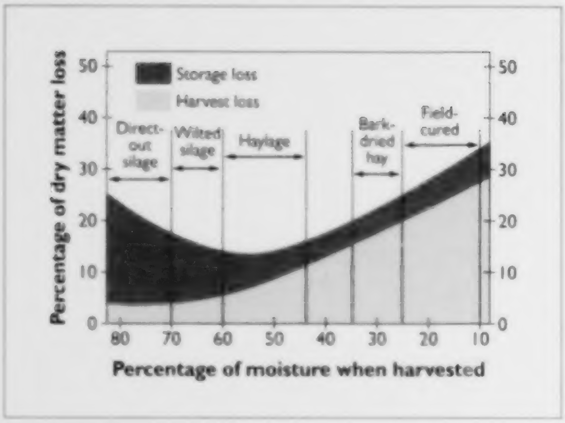


Figure 3–2. Estimated Hay and Haylage Harvest and Storage Losses
Adapted from Hoglund, 1964

Fast drying is a key to successful haymaking. In Ontario, good haymaking periods without rain can often be very narrow. There is a constant struggle between getting the hay dry enough to bale before the next rain, or baling before the hay is quite dry enough and getting mouldy, dusty hay. Conditioning and raking has to be balanced against excessive leaf loss.

Cutting and Conditioning

Disc mowers perform more dependably than sickle mowers in situations where forage is lodged, or in very thick grass stands. Disc mowers can operate at higher speeds and capacity but are more expensive.

Hay conditioners crush, crimp or flail the plant stems and speed up drying. Quicker drying reduces the risk of the hay being rained on and synchronizes the drying of leaves and stems, which can reduce leaf shatter. Grasses generally dry faster than legumes. Conditioners should be maintained and adjusted to ensure the optimal amount of conditioning. See the owner's manual.

Swath windrows should be left as wide as feasible after cutting in order to speed drying time and minimize respiration losses of soluble sugars. A wide swath decreases forage density and windrow humidity and increases the evaporative surface exposed to sunshine. Most mower-conditioners have an easy swath width adjustment.

Harvest Losses

There are a number of losses associated with the production of dry hay (less than 20% moisture). Since the leaves contain about half of the dry matter and two-thirds of the protein, leaf loss has significant impacts on yield and quality.

Table 3–11. Potential Haymaking Losses

Source of Loss	% Loss of Dry Matter
Respiration	2–16
Cutting and conditioning	2–5
Raking	5–25
Bailing small bales	3–8
Bailing large bales	1–15
Transportation	1–10
Potential total loss	10–71

Respiration

Even after cutting, forages continue to respire and consume sugars until the moisture content drops below 40%. Under relatively fast drying conditions, these losses can be kept to a minimum: 2%–8% of total dry matter. Under poor drying conditions (low temperature, high humidity, etc.), the plants take longer to dry down to 40% moisture, and dry matter losses as high as 16% have been measured.

Weathering

Rainfall on windrowed hay sustains respiration and causes other losses. Nutrients such as simple sugars are leached from the leaves, and leaf loss increases, resulting in reduced digestibility. Sugars leached from the leaves results in less dilution and can increase the percent protein. However, the amount of protein produced per acre is reduced, and protein digestibility also decreases. Weathering also decreases the amount of hay the animals will eat, and rain damage increases the amount of mould on hay in the swath, which can make it less palatable and unsuitable for the horse market.

Mechanical Losses

As forages cure, the leaves and small stems become more brittle. Any mechanical operation, such as raking or tedding, done on material having less than 40% moisture causes leaf losses. Leaf losses increase as moisture content declines. If possible, rake when hay is moist. Leaf loss can be reduced by raking lower-moisture hay in the morning while dew is still present, slowing the speed of rotary rakes and turning a windrow with an invertor. Tedders are more commonly used on grass hay crops and can result in significant alfalfa leaf loss at lower moistures. Losses at the baler pick-up and in the baling chamber can be reduced by raking light windrows together at higher moisture and by traveling at maximum ground speed.

Potential Hay Harvesting Losses

The losses from haymaking that have been reported in research trials are summarized in Table 3–11, *Potential Haymaking Losses*, this page.

Table 3–12. Storage Moisture Guidelines

Bale Type	Storage Moisture (%)
Small square bales	15–18
Large round bales – soft core	13–16
Large round-bales – hard core	12–15
Large square bales	12–15

Source: Clarke and Stone, OMAFRA, 1993.

Storage Losses

Hay that is sufficiently dry and is stored under cover will normally experience minimal storage losses. These losses can usually be attributed to handling losses as the bales are moved.

Hay having high moisture is at risk from spoilage due to micro-organisms metabolizing sugars in the hay and giving off heat. The amount of potential damage to the hay is related to:

- percentage of moisture in the hay
- density of the bale and how tightly bales are packed in the mow
- temperature and humidity of the outside air

Dry hay storage moistures guidelines for various bale types are outlined in Table 3–12, *Storage Moisture Guidelines*, this page.

Storing bales inside or covering large bales dramatically reduces spoilage losses. In a 1.5-m (5-ft) round bale, 19% of the hay is in the outside 15 cm (6 in.), and 36% in the outside 30 cm (12 in.). Situate outside storage on a well-drained site. See the OMAFRA Factsheet, *Big Bale Hay Storage*, Order No. 88-052, or visit the website at www.ontario.ca/crops.

Feeding Losses

Feeding losses of dry hay can be quite significant. Feeding losses can be greater than 50% when hay is fed to cattle on the ground without a feeder. Cone and ring feeders have less waste than trailer or cradle feeders.

Hay Heating

The process of wet hay heating up and then burning is typically called spontaneous combustion. Spontaneous heating and combustion occur when sufficient moisture, oxygen and organic matter are present together to support the growth of bacteria and moulds. The reaction can be self-sustaining. The gases produced will ignite if they reach a high enough temperature. Care must be taken to ensure that hay is sufficiently dry to be baled and stored. Spontaneous combustion for hay usually occurs within the first 2 months of storage.

Usually, the first indication that the hay may be hot is the release of an odour similar to pipe tobacco and possibly steam rising from the mow. Mow temperatures can be monitored by pushing a pointed probe into the hay and then lowering a candy thermometer into it on a string. Never take temperatures alone, because fire pockets can develop, and there is a risk of falling in.

The following temperature guidelines can be used for monitoring hay mows:

- 65°C — Entering the danger zone. Take temperatures daily.
- 70°C — **Danger!** Inspect every 4 hours to see if the temperature is rising.
- 80°C — **Fire pockets may form.** Call the fire department.
- 100°C — **Critical!** In the presence of oxygen, ignition will take place.

If a thermometer is not available, an iron or copper rod pushed deep into the hay for about an hour will give an indication of the hay's temperature. If it is almost too hot to hold onto with bare hands once it is removed, there is a problem.

See the OMAFRA Factsheet, *Silo and Hay Mow Fires on Your Farm*, Order No. 93-025, or visit the OMAFRA website at www.ontario.ca/crops.

Propionic Acid Hay Preservatives

The weather in Ontario makes it difficult to field-cure dry hay on a consistent basis. Propionic acid hay preservatives can help reduce the risks of heating, mould, spoilage and dry matter losses associated with baling hay at higher moisture.

Propionic acid is an organic acid that acts as a fungicide, inhibiting the growth of aerobic micro-organisms that can cause heating and moulding. The propionic acid inhibits mould growth while the bales "sweat' and "cure" down to safe moisture levels by dissipation and evaporation. Do not confuse proprionic acid hay preservatives with enzyme, bacterial inoculant or nutritive additive products, which differ in modes-of-action and effectiveness.

Propionic acid products are registered by the Canadian Food Inspection Agency (CFIA). Be sure to read the label, observe concentration rates and follow labelled application rates. Propionic acid hay preservative products now available are buffered to a pH of approximately 6.0 and do not irritate the skin and eyes as the older products did. They may also include acetic and citric acids, as well as a surfactant and colouring.

Hay treated with buffered propionic and other organic acid products is safe to feed to livestock. Propionic and acetic acids are organic acids that are also produced by microbes in the rumen (and the cecum and colon of horses) and then used by the animal as part of the digestion process.

Since the moisture content at baling determines the amount of preservative, it is important that moisture content be measured accurately. Hand-held moisture probes may not be accurate enough to fine tune the amount of preservative needed. There can be as much as 10%–15% moisture difference within a swath. This variation can lead to pockets of wet material that will be inadequately treated. To determine the range in moisture content, make a few bales and take samples from them rather than the swath. There is a difference between average moisture content and maximum moisture content. Adjust the rate to maximum rather than average moisture content.

Propionic acid is sprayed onto hay as it enters the baler. Basic systems include a tank, pump and nozzles. Automated computerized application systems are available that include in-chamber moisture sensors that automatically adjust application rates. These systems are virtually standard on large square balers

For more information on preventing mouldy hay using propionic acid, visit the OMAFRA website at www.ontario.ca/crops.

Anhydrous Ammonia Treatment of Poor Quality Hay

Anhydrous ammonia is a preservative that will increase the crude protein content and digestibility of poor-quality hay. The recommended rate of application is 1% of dry hay weight, and the hay must be no wetter than 30% moisture. The hay should be covered with plastic to retain the ammonia, otherwise the preservative effect is only temporary.

As a preservative, anhydrous ammonia is not as good as propionic acid and should not be used on high-quality hay. **Its use on high-quality hay has caused "crazy cow" syndrome where animals run wildly into obstacles, go into convulsions and possibly die.** High-quality ammoniated hay should not be fed to animals with a high nutritional demand such as lactating cows.

Barn Hay Dryers

Barn hay drying systems are installed as a component in the production of quality hay. A properly managed hay-drying system reduces field curing time and the risk of losses due to rain, minimizes leaf loss and eliminates the danger of fire due to spontaneous combustion (see *Hay Heating*, opposite page). A barn hay dryer makes use of a fan-and-air-duct distribution system to force outside air through partially dried hay placed in storage. This movement of air through the hay removes heat and excess moisture and will eventually complete the drying process that started in the field.

Horse Hay

The quality parameters for horse hay are different than for hay produced for cattle and sheep. Many horse owners determine the quality of hay primarily by its freedom from mould, dust and weeds, and a green colour. Hay that is not adequately dry at baling will mould, which results in dusty hay that causes respiratory problems. Horse hay should not have been rained upon. Most horses do not require hay with high protein content, and many recreational horses do not have high energy requirements. A timothy-alfalfa mix is common. Horse hay can often be harvested later in the haying season when the plants are more mature, giving some flexibility in haying and less chance of being rained upon. This will result in a higher yield of dry matter, but the hay will be lower in protein and energy.

There is often a market for horse hay in small square bales, as many horse owners do not have the equipment to handle large bales. There is also a growing market for horse hay in large square bales for both domestic and export markets. More information on horse hay is available on the OMAFRA website at www.ontario.ca/crops.

Haylage and Corn Silage

Storing forage as hay-crop silage, or "haylage," has advantages over storing it as hay. These advantages include:

- lower harvest losses
- lower labour costs because all operations can be mechanized
- less dependence on good drying conditions, which allows the crop to be cut at the desired maturity

Corn silage is a popular forage crop due to yield, palatability, high-energy density and single harvest convenience.

Silage Crop Storage Types

The most common types of silage storage are:

- vertical (tower) silos
  - conventional open top
  - oxygen limiting (sealed)
- horizontal silos
  - bunker
  - piles

- silage bags
- large bale haylage (baleage)

When to Harvest Corn Silage

Harvesting corn silage at the correct moisture is critical for feed quality. The best livestock performance and corn silage fermentation usually occur when whole plant moisture is 65%–70%. This corresponds well to horizontal and bag silos, but silage may have to be somewhat drier in tower silos to prevent seepage. See *Maintain Correct Moisture Content*, opposite page.

Kernel Milk Line

The kernel "milk line" has often been used to determine when to harvest corn silage, but this method has some limitations. The technique involves breaking a cob in half and looking at the kernels. After denting (0% milk line), a whitish line can be seen on the kernels. This line is where the solid and liquid parts of the kernel are separated while maturing and drying. This line will progress from the tip to the base. When it reaches the base (100% milk line), a black layer will occur. The traditional recommendation has been to harvest from one-half to two-thirds milk line.

There is considerable variation in the percentage kernel milk line and the moisture percentage of the whole plant. Whole plant moisture at one-half milk line may be too wet in some situations and much too dry in others. When the weather is relatively dry, the whole plant moisture may be lower than expected at any given milk line position. There are also hybrid differences in kernel milk line, due to the "stay-green" characteristic. A high stay-green rating means there is faster grain dry-down relative to stover dry-down. This is desirable in a grain hybrid, because as the grain dries, the stalk stays green and healthy, and broken stalks and lodging in late season are less likely. Many silage-only hybrids have a low stay-green rating, so the grain will have higher moisture relative to the whole plant. Lodging is less important in silage because of the earlier harvest, and having more moisture in the grain portion increases starch digestibility. Hybrids with high stay-green ratings may have milk lines that are more advanced relative to whole plant moistures. Silage-only hybrids that have lower stay-green ratings will be ready to harvest at a less advanced milk line. Check with your seed company representative for historic milk line recommendations for a given hybrid.

Measuring Percent Moisture

The most accurate method of determining when to harvest silage corn is to measure the moisture content.

- Sample at least 10 plants from the field, avoiding the headlands. Watch for moisture variability within fields.
- Chop a sample using a harvester or yard chipper. The finer the sample is chopped, the easier it will be to dry and the more accurate the result.
- Use a commercial forage moisture tester, microwave or laboratory to determine the percentage of dry matter. Moisture testers and microwaves may not remove all the residual moisture in the sample and may underestimate moisture by about 3%.

Shortly after denting, when the milk line is about 20%, whole plant moisture can be determined. In a typical year, corn silage at this stage dries approximately 0.5% per day. Therefore, if the sample was 70% moisture, and 65% moisture is the target, harvest should be done about 10 days after the corn was sampled. In dry years, the drying rate will be more rapid; in wetter years, the drying rate will be slower. Moistures can be checked again closer to harvest if necessary.

Silage Fermentation

When forage is first put into a silo, conditions are aerobic (oxygen is present in the silage mass). Aerobic bacteria produce some heat as they break down carbohydrates and sugars into carbon dioxide and water and use up the trapped oxygen.

When the oxygen has been consumed, the silage becomes anaerobic, which promotes the growth of anaerobic bacteria. These organisms convert the carbohydrates and sugars to organic acids that preserve the silage. In addition, some of the protein is broken down into amino acids, ammonia and other non-protein, nitrogen compounds. During this ensiling process, the acids lower the pH, while the production of ammonia tends to raise it. The production of ammonia increases the amount of time it takes to reach a stable pH.

In 2 or 3 weeks, the silage reaches a stable pH of 4.0–5.0, and all bacterial and enzymatic activity stops. Once this stable pH has been reached, further breakdown of nutrients and spoilage is prevented, and the silage will keep for extended periods of time, provided air is excluded.

Silage Storage Losses

Most silage storage losses are associated with exposure to oxygen.

Respiration Losses

When plants are harvested and ensiled, the plant cell respiration continues, resulting in a breakdown of sugars and other carbohydrates.

Fermentation Losses

Primary and secondary fermentation result in varying amounts of fermentation losses. An extended period of fermentation can result in an excessive breakdown of sugars. Some types of bacteria are less efficient than others. At moistures over 70%, a clostridia fermentation can occur, which results in high levels of butyric acid.

Seepage Losses

When excessively wet material is put into a silo, the weight of the material can squeeze moisture from the silage at the bottom. The seepage carries sugars and other nutrients out of the silo. In addition, seepage can lead to excessive corrosion of the silo walls, reinforcing rods and result in the possible collapse of the silo. Silo seepage can also lead to fish kills if it enters a watercourse. See the OMAFRA Factsheet, *How to Handle Seepage From Farm Silos*, Order No. 04-031, or visit the website at www.ontario.ca/crops.

Heating

Heating causes plant sugars and proteins to combine and form indigestible compounds. This results in a "toasting" or browning of the silage and reduced protein digestibility. In extreme cases, because the silage is too dry or a continuous supply of air is getting into the silage, spontaneous combustion can lead to a fire. Such fires can happen at any time of the year and are almost impossible to extinguish.

Surface Spoilage

Less compacted, uncovered silage spoils because continuous exposure to oxygen results in the growth of aerobic micro-organisms (yeast, moulds and aerobic bacteria).

Feed-Out Losses

When a silo is opened to remove feed, there can be further losses in feed value. These losses are caused by moulds and yeast that become active in the silage when it is again exposed to oxygen. Secondary losses can occur at the cut face of the silage mass or in the bunk while being fed.

Recommended Silage Management Practices

Maintain Correct Moisture Content

- conventional upright silos: 60%–65%
- horizontal silos: 60%–70%
- oxygen-limiting silos: 50%–60%
- bag silos: 60%–70%
- wrapped large bale haylage: 40%–60%.

Silage that is too dry will result in poor packing and air exclusion, poor fermentation and the production of heat. If haylage becomes too dry, cut fresh material and continue to fill the silo by alternating fresh and dry loads. The addition of water will not increase the moisture of dry silage. The water is not absorbed by the silage and can easily run off; a garden hose does not deliver enough water to make an appreciable difference in moisture content. Silage harvested at moisture percentages greater than 70% can result in seepage and an undesirable clostridia fermentation that results in butyric acid formation, high dry matter losses and poor feed quality, palatability and intake potential.

Use Proper Length-of-Cut

Fine chopping helps to exclude air by allowing tighter packing but must be compromised with rumen function requirements. The actual particle length will be different from the theoretical length-of-cut (TLC) and can be checked with a particle length separator.

With haylage, a 10-mm (7/16-in.) TLC is usually desirable. Low moisture silage may require a shorter TLC (6 mm or ¼ in.) to ensure adequate packing. The length of cut is probably more critical with horizontal silos, although it is still important with upright and sealed silos. Harvester blades must be sharp and correctly set. Chopping finer than 6 mm (¼ in.) is not recommended since it doesn't improve packing, requires more horsepower and may result in nutritional problems.

Corn silage "kernel processors" use rollers attached to the chopper to break cobs, crack kernels and shred stalks. The TLC recommended with processors is 19 mm (¾ in.) rather than 10 mm (7/16 in.) without a processor. Processors may be more beneficial with relatively dry, hard-kernel, textured corn.

Fill Rapidly

Fill silos as quickly as possible to speed fermentation and minimize spoilage. If filling is delayed for a few days, the silage should be covered with plastic to reduce the chance of spoilage. In an upright silo, the silage is not compacted until a considerable depth of material has been put in the silo. The top part of the silage will be less dense and hold more air that could cause heating and loss of quality.

Pack Horizontal Silos Well

Bunk silos should be filled from back to front so that a "progressive wedge" shape is created, rather than filling from bottom to top. As the silo is filled, it should be packed in relatively thin layers (15 cm or 6 in.) to obtain good air exclusion. Sufficient tractor weight and packing time are critical. This may mean adding more packing tractors to increase packing time per tonne.

Maintain Tower Silos

A tower silo can act as a chimney. If air can get in, it will move up through the silage mass, which could lead to spoilage, heating of the silage and, in extreme cases, fire. Cracks in the silo walls or around the doors should be caulked or reconditioned to prevent the entry of air. Without good distribution, the lighter forage material will collect along the wall, leading to poor packing.

Seal Silos Well

- Covering and sealing with UV-protected silage grade 6-mil plastic is essential in horizontal silos. The plastic should be held firmly in place. Old tires (split) placed closely together (touching) or other commercial products work very well. The plastic should not be allowed to flap in the wind, because it then acts as a bellows and pumps air into the silage rather than excluding it. Plastic should be placed so that rainfall runs off and away from the silage, rather than down the walls to collect at the bottom.
- In conventional tower silos, forage at the top has low density that air can penetrate. To reduce spoilage until fermentation is complete, silage should be covered with plastic and weighted down by a few centimetres of silage. Take precautions to avoid silo gas. (See *Silo Gas*, opposite page.)
- In sealed silos, the hatches should be closed at night and during interruptions in filling. When filling is complete, the hatches should be closed immediately.

Allow Complete Fermentation

Silage fermentation requires up to 21 days. To ensure silage stability and maximize feed bunk life, do not feed out of the silo until this process is complete.

Feed Out Quickly to Minimize Spoilage

The re-exposure of the silage to air at feed-out can result in the growth of moulds, yeast and aerobic bacteria. Slower feed-out rates increase the likelihood of aerobic spoilage. During hot, humid weather, larger feed-out rates are required to stay ahead of the spoilage. Size silos accordingly. Empty tower silos at a rate of at least 5 cm (2 in.) per day in winter and 7–10 cm (2¾–4 in.) per day in summer. Horizontal silos should be fed out at a minimum rate of 10–15 cm (4–6 in.) per day, depending on the season. Feeding mouldy silage is not recommended because it reduces intake and can cause nutritional problems.

Manage Silage Face to Minimize Spoilage

The silage face should remain tight and smooth to limit the penetration of air. Avoid fracturing the silo face by running at it with the front-end loader and using a lifting action. Minimize fracturing by scraping down the face with the front-end loader and allowing the silage to fall to the floor. Block cutters or shear buckets are other options. Uncover and loosen only as much silage as is required.

Silage Bacterial Inoculants

Silage inoculants are additives containing anaerobic lactic acid bacteria (LAB) that are used to manipulate and enhance fermentation in haylage (alfalfa, grass, cereal) and corn silage A more efficient fermentation resulting in more lactic acid and less acetic, propionic and butyric acids, is the desired result. The primary expected benefits are reduced fermentation losses (shrink) and often improved animal performance and feed efficiency. Bunk life may or may not be improved, depending on the pH and acetic acid levels.

The most common LAB in commercial inoculants are *Lactobacillus plantarum, Enterococcus faecium,* various *Pediococcus* species and other *Lactobacillus* species. Species and specific strains of LAB in commercial inoculants have been selected because they grow rapidly and efficiently, and produce primarily lactic acid. They increase the fermentation rate, causing a more rapid decline in pH, with a slightly lower final pH. The products of fermentation are shifted, resulting in more lactic acid and less acetic acid, ethanol and carbon dioxide. Lactic acid is stronger than acetic acid and contains almost as much energy as the original sugars.

If there is a high natural population of anaerobic bacteria, an inoculant is less likely to dominate the fermentation and provide a benefit. The natural population is increased by higher-than-average wilting temperatures, longer wilting times, rain during wilting and higher moisture contents during chopping. The application of a silage inoculant will not overcome the effects of poor silage management or poor weather conditions. These products are most effective when applied to high-quality forage under best management.

LAB inoculants are usually less beneficial in corn silage than in haylage. Corn silage is also more susceptible to secondary yeasts and moulds while being fed, resulting in shorter "bunk life." Lactic acid is preferred by yeasts when exposed to oxygen, whereas acetic acid can inhibit yeasts. For this reason, inoculants have been developed for corn silage and high moisture corn that contain *Lactobacillus buchneri* as well as LAB. Late in the fermentation, the *L. buchneri* utilize lactic acid to produce some acetic acid to reduce the growth of yeasts and spoilage at feedout.

Forage additives, including silage inoculants, must be registered with the Canadian Food Inspection Agency (CFIA) to be sold in Canada. To receive a "permanent" registration, companies must provide research that substantiates a nutritional label claim. Where research has been conducted but the results are not conclusive, products may be eligible to receive a "temporary" registration for up to 3 years to conduct additional research that substantiates a label claim. Temporary registration numbers start with a "T." Ask company representatives to provide independent research that substantiates their claims for the product. It is important

Table 3–13. Common Silage Problems and Causes

Problem	Causes
Hot or mouldy silage	• Low moisture content • Slow silo filling • Air leaks • Poor compaction • Slow feed-out
Caramelized (dark, tobacco smell)	• Heat damage caused by low moisture or poor compaction
Frozen silage	• Moisture too high • Poor fermentation
Vinegar odour	• Excess acetic acid caused by low plant sugars or poor fermentation
Seepage	• Moisture too high
Rancid odour	• Butyric acid from *Clostridia* fermentation caused by too high moisture
Alcohol odour	• Yeast fermentation from slow feed-out, oxygen or low-lactic-acid bacteria

that the product is labelled for the crop being ensiled, and that directions for storage and use are followed.

Common Silage Problems and Causes

There are several common problems associated with silage. Table 3–13, *Common Silage Problems and Causes*, this page, lists potential reasons for these problems. A fermentation profile analysis, which determines relative amounts of lactic acetic, butyric and proprionic acids, as well as ammonia content and pH of silage, can be used to diagnose suspected problems. A fermentation analysis reflects the quality of the ensiling process and can be used as an aid in improving future silage management practices.

Silo Gas

Nitrogen dioxide, NO_2, is a dangerous chemical asphyxiant that is produced as a result of chemical reactions that take place almost immediately after plant material is placed into a silo. Even short-term human exposure can result in sudden death. It has a characteristic bleach-like odour and may be visible as a reddish-brown haze. It is heavier than air; therefore it will tend to be located just above the silage surface. It may also flow down silo chutes and into feed rooms.

Weather conditions and cultural practices will affect the amount of nitrates in plant material, which in turn will set the stage for the production of NO_2 in the silo. For example, a dry period during the growing season followed by abundant rainfall will encourage a corn crop to take up high levels of dissolved nitrates. If the corn is harvested before the nitrates can be converted to proteins, nitrous oxide (N_2O) and nitric oxide (NO) are produced. Unstable NO combines with oxygen to form deadly nitrogen dioxide.

When inhaled, NO_2 dissolves in the moisture on the internal lung surface to produce a strong acid called nitric acid. Nitric acid burns the lung tissues, which is followed by massive bleeding and death. Repeated exposure to lower concentrations of NO_2 will cause chronic respiratory problems, including shortness of breath, coughing and fluid in the lungs. Seek medical attention immediately upon exposure.

Silo Gas Precautions and Procedures

- Post a "Silo Gas" warning sign in a visible location near the silo.
- Do not allow children or visitors near the silo for 3 weeks after filling has been completed.
- Contact your local fire department to determine if pressure-demand remote breathing apparatus is part of their emergency equipment. SCUBA equipment is not suitable, because the air tank is too big for climbing the silo chute or the outside ladder-cage.
- Provide sufficient feed room ventilation to exhaust any silo gas that may have spilled from the silo.
- During filling, adjust the distributor as needed to level silage. Do not level material by hand.
- If it is necessary to enter the silo when filling is complete, do so immediately following the last load, on the same day. Leave the blower running while inside the silo.
- Do not attempt silo entry without wearing a lifeline that is in the hands of sufficient outside help to pull you to safety.
- If it becomes necessary to enter an oxygen-limiting silo, it is essential that an external air supply be worn.
- A top unloader can usually ventilate a silo effectively. However, if it becomes necessary to service a defective unloader, assume that gases are present. To expel gases before entering, run the forage blower with the chute doors closed and the roof vent open. If the head space is greater than 5 m (16 ft), attach a tube adapter to the blower pipe. For a 7.2-m (24-ft) diameter silo with 5–10 m (16–33 ft) of head space, increase the ventilation time. Leave the forage blower running while in the silo.

See the OMAFRA Factsheet, *Hazardous Gases*, Order No. 04-087, or visit the website at www.ontario.ca/crops.

Large-Bale Haylage (Baleage)

Large-bale haylage, or "baleage," has become popular as an option for storing excellent-quality forage. By making large bales into haylage, a farmer can be more aggressive and consistent in cutting schedules as it reduces the weather risk factor. Some farmers use this as their main storage system, but it can also be a flexible second system of storage when silos are full and the weather doesn't permit drying. It produces a long-stem haylage. Plastic bagging or plastic wrapping is used.

The system makes use of equipment such as large round and square balers, which are readily available. Baleage may be fed using the same equipment as dry, large bales. This provides flexibility, to make as little or as much large bale silage as the weather dictates. Heavier equipment and four-wheel-drive tractors may be required when handling the heavier bales.

The cost and disposal of the plastic coverings have been major concerns. Cost is rationalized by considering the higher protein and energy value of the stored forage and the importance of the storage itself. Consider reduced harvesting losses and the higher quality of the whole forage crop as the harvest is moved ahead when determining the cost benefit of the system. See the OMAFRA Factsheet, *Recycling Farm Plastic Films*, Order No. 95-019, or visit the website at www.ontario.ca/crops.

With large-bale haylage, there is less or incomplete fermentation, resulting in a higher pH, or a less acidic environment, and a more unstable silage than conventional haylage. Greater emphasis must be put on good silage-making processes, especially the exclusion of oxygen. Adjust the length of storage time and how long the bales are exposed to oxygen before feed-out to weather conditions.

Successful use of baleage involves the following management practices:

- Make firm, dense, uniform bales. Large squares are usually denser than rounds.
- Bale at 40%–55% moisture. Lower moistures can work, particularly with large square bales wrapped with adequate plastic but are at a greater risk of spoilage.
- Use enough plastic! Bales should be wrapped air-tight with a least 6 mils of plastic film (6 wraps of 1 mil or 4 wraps of 1.5 mil). To ensure against tears, 8 mils is preferable, particularly with drier baleage.
- Wrap round bales within 2 hours of baling on hot days and within 4–12 hours at cooler temperatures. Large square bales are more forgiving of later wrapping.
- Avoid using hay that was rained on.
- Avoid raking to minimize contamination by *Clostridia* bacteria. Do not incorporate soil into the windrow with the rake.
- Avoid fields where manure has been applied since the previous cut.
- Avoid mature hay with low sugar content.
- Be sure to repair all tears and holes in the plastic.

See *Maintaining Quality in Large Bale Silage* on the OMAFRA website at www.ontario.ca/crops.

Other Crop Problems

Insects and Disease

Severe infestations of disease and insects that result in reduced stand vigour, reduced root reserves and slow regrowth will increase the risk of winterkill. Potato leafhopper control can be important in reducing winterkill, particularly in the seeding year (see *Potato Leafhopper*, on page 215).

Figure 3–3, *Forages Scouting Calendar*, opposite page, shows insects and diseases that could be causing the symptoms in the field. Individual descriptions of insects and diseases, scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, and Chapter 14, *Diseases of Field Crops*.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

Forage Winterkill

Winterkill of forage stands can cause serious problems on livestock farms and can be a limiting factor in alfalfa production. It can result in lower-quality feed, shortages of feed, disruption of the rotation and additional costs for reseeding lost stands. With forage production, it can sometimes be difficult to optimize the competing demands of quality, yield and persistence. Determine how much forage persistence is needed and manage the risks accordingly.

Causes of winterkill include:

- smothering due to flooding or ice sheet formation
- heaving caused by freezing and thawing and inadequate drainage
- root injury due to low temperature
- low fertility
- poor cutting management
- diseases and insects

Some forage species are hardier than others. Much of the concern over winterkill centres around alfalfa. The legumes birdsfoot trefoil, red clover, wild white clover and alsike will tolerate more adverse winter conditions than alfalfa or ladino clover. The grasses timothy, reed canarygrass, bluegrass and bromegrass rarely winterkill; thus their use in mixtures gives stand insurance. Orchardgrass and perennial ryegrass are more likely to be killed by icing or low temperatures.

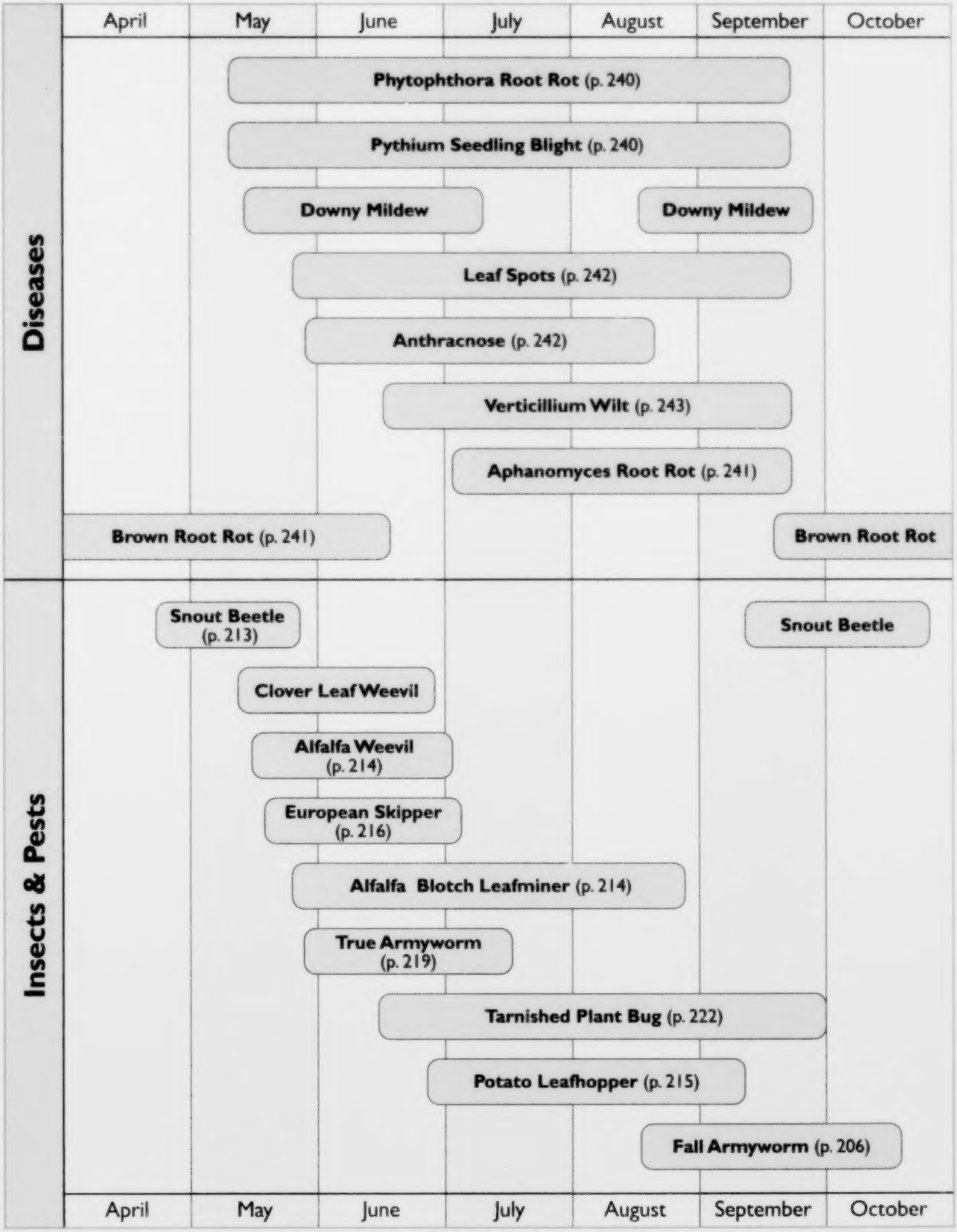


Figure 3–3. Forages Scouting Calendar

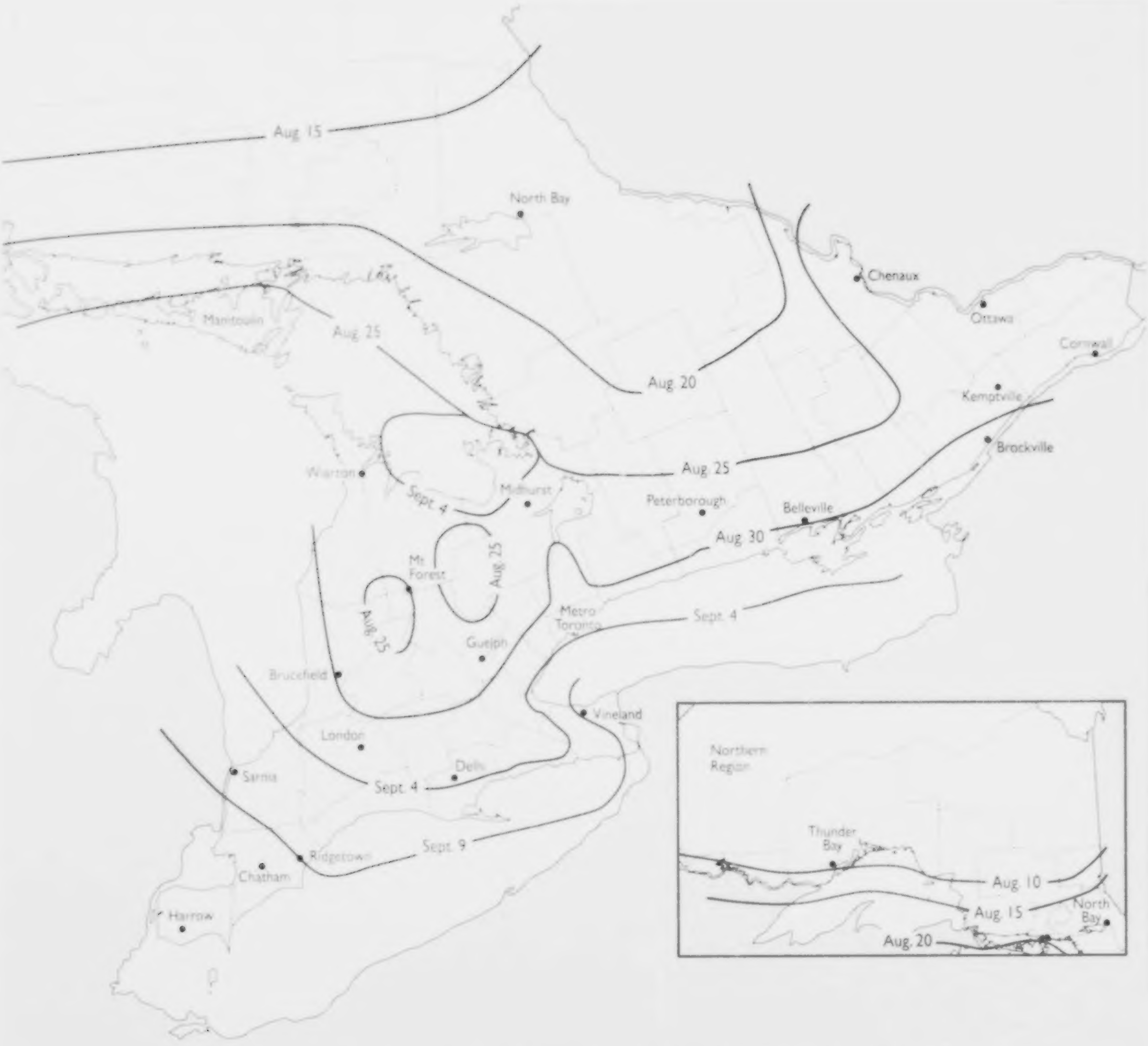

Aug. 15
North Bay
Chenaux
Ottawa
Cornwall
Manitoulin
Aug. 25
Aug. 20
Kemptville
Brockville
Wiarton
Aug. 25
Sept. 4
Midhurst
Peterborough
Belleville
Aug. 30
Mt Forest
Aug. 25
Aug. 25
Metro Toronto
Sept. 4
Guelph
Brucefield
Vineland
London
Sarnia
Delhi
Sept. 4
Ridgetown
Sept. 9
Chatham
Harrow
Northern Region
Thunder Bay
Aug. 10
Aug. 15
North Bay
Aug. 20

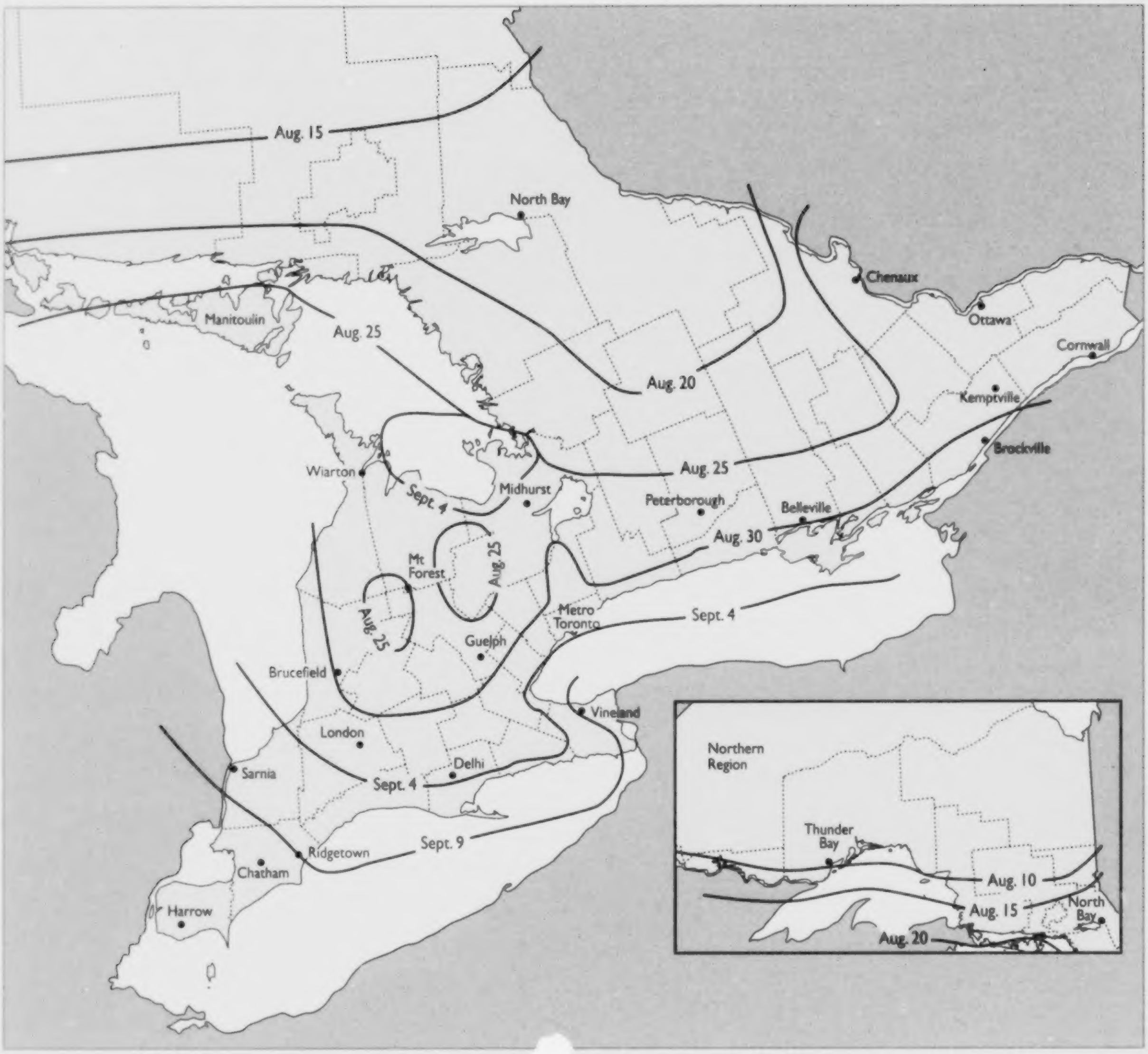
Figure 3–4. Start of the Critical Fall Harvest Period for Alfalfa

Hardening is the process of cold tolerance development initiated by shorter fall days and cooler temperatures. During the hardening process, plants store carbohydrates in crowns and taproots. The starch is converted to sugars, which gives the plants some protection from freezing. Plants also lose some cellular water to reduce freezing damage. Long fall periods with cool, dry, sunny conditions favour winter hardening.

Factors That Affect Winter Survival

Critical Fall Harvest Period for Alfalfa

Harvesting before the critical fall harvest period for alfalfa, also known as the "fall rest period," allows the plants to regrow and build sufficient root energy reserves for over-wintering. Adequate root reserves are necessary for winter survival and persistence, as well as for vigorous spring growth and good first-cut yields. The critical fall harvest period is the approximately 6-week window before the historical average killing frost, and varies with location. See Figure 3–4, *Start of the Critical Fall Harvest Period for Alfalfa*, this page, to determine the critical fall harvest period in your area. The risk of alfalfa winterkill increases by harvesting during this period and should be weighed against the immediate need for forage. Yield sacrificed by not harvesting during the critical fall harvest period is usually easily regained in the first-cut yield the following year. See the OMAFRA Factsheet, *Risk of Alfalfa Winterkill*, Order No. 91-072, or visit the OMAFRA website at www.ontario.ca/crops.


Aug. 15
North Bay
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Cornwall
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Kemptville
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To ensure persistence and succeeding yields, consider the risks before harvesting alfalfa during the 6-week period following the date shown on the map for each region.

Winter-Tolerant Alfalfa Varieties

See the Ontario Forage Crop Variety Performance brochure available at OMAFRA Resource Centres or at www.uoguelph.ca/plant/performance_recommendations/ofcc/ofcc.htm. High alfalfa yield indexes in the third and fourth year indicate high relative persistence. This is a composite measure of a number of production characteristics, including winter-hardiness, cold tolerance, disease resistance and yield. In general, varieties that have "resistant" or "highly resistant" ratings for disease have a lower risk of winterkill.

Snow Cover

Adequate snow cover of at least 15 cm (6 in.) insulates the alfalfa crown and root at moderate temperatures. A lack of snow cover can expose alfalfa crowns to temperatures less than –15°C. This results in freezing damage to plant cells and eventual plant death. The insulation effect from snow also reduces soil temperature fluctuations and risk from heaving. Fluctuating winter temperatures with lows below freezing and highs greater than 5°C, without snow cover, can cause plants to break dormancy and become more susceptible to freezing.

Ice Sheeting

Fast melting of snow followed by cold temperatures can result in ice sheeting, which smothers the plants by restricting oxygen. Ice sheeting also causes freezing damage to alfalfa crowns, due to the poor insulating ability of ice.

Leaving Fall Growth to Hold Snow

After a hard fall frost, alfalfa can be harvested without lowering root reserves, but there are disadvantages. Leaving the fall growth will help catch snow, which insulates the soil from cold temperatures. The stubble also helps alfalfa plants survive ice sheeting by protruding through the ice, allowing the movement of air for respiration. Unlike grasses, fall regrowth of alfalfa does not cause "smothering," however, ice sheeting does.

Soil Drainage

Both surface and subsurface drainage are essential to alfalfa winter survival. Heaving can occur on heavy soils with poor drainage since repeated freezing and thawing cause the taproot to be pushed out of the soil (see Plate 22 on page 282). Plants heaving more than 2.5 cm (1 in.) will dry out, have broken taproots and lateral roots, and elevated crowns. These plants will die or be severely stunted. Surface drainage is a bigger issue on flat land than rolling land, because with frozen ground, water cannot drain off the field, resulting in ice sheeting.

Cutting Management

Frequent harvests with short cutting intervals put stress on alfalfa that can reduce winter survival and first-cut yield the following year. Conversely, a long interval between cuttings will rebuild plant reserves and enhance winter survival. Some growers place more emphasis on high-yielding, frequently cut, high-quality stands that last for 3 years and are less concerned about alfalfa persistence. Intervals of less than 35 days between cuts increases the risk of winterkill. Allowing the final cut to show some flower before harvest to ensure adequate root reserves can be a compromise between quality and winter survival.

Soil Fertility and pH

A low soil-potassium level is a major factor leading to loss of alfalfa in a stand, particularly on loams and sandy loams. Adequate soil potassium levels allow alfalfa to store sufficient carbohydrates in the roots to resist low-temperature injury and act as the energy source for vigorous spring growth. Soil-sample forage fields regularly and fertilize them according to recommendations. Apply the fertilizer before the start of the critical fall harvest period to allow for sufficient plant uptake.

However, high soil-potassium levels can result in luxury consumption of potassium by alfalfa and subsequent nutritional problems when fed to dairy cows prior to calving. Potassium applications on soils testing over 150 ppm will not significantly increase winter hardiness and are not recommended.

Boron deficiency can also lead to stunted alfalfa growth during midsummer dry periods and thus weaker plants going into winter. For soils low in pH, add lime the year prior to seeding (see *Fertility Management*, on page 66).

Table 3–14. Desirable Alfalfa Stand Plant Count

	Plant Count	
	Plants per m^2	**Plants per foot^2**
New seeding	215	20 +
Year 1	129–215	12–20
Year 2	86–129	8–12
Year 3 or older	54	5

Assessing an Alfalfa Stand for Winter Survival

Future yield potential can be estimated by counting the number of plants or stems per square metre, but the health of crowns and roots is extremely important. Stem counts are more accurate than plant counts, but in early spring it may only be possible to count the number of crowns. Be prepared to replace an older stand if it has less than 43 plants/m^2 (4 plants/ft^2). See Table 3–14, *Desirable Alfalfa Stand Plant Count*, this page.

Dig several plants to determine the health of the crown and root. Healthy crowns are large and symmetrical and have many shoots. Cut a root open lengthwise. Healthy roots will have a white or creamy colour inside, and are firm and resistant to pealing when scratched with a thumbnail. Dying plants will have a discoloured crown and root and a spongy texture. Check for bud or new shoot vigour. Plants with broken taproots from heaving may green up but die later. Slightly heaved plants can survive, but their longevity and productivity will be reduced.

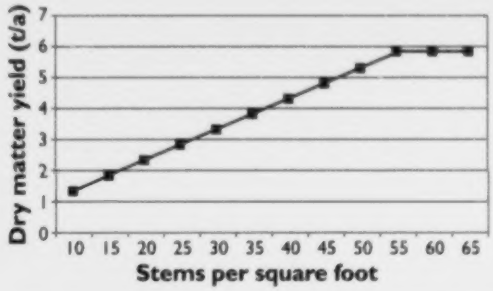


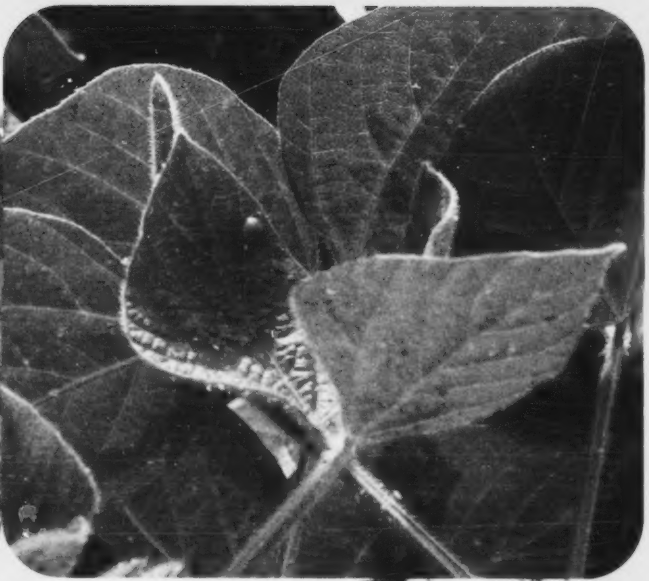
Figure 3–5. Alfalfa Yield Potential at Various Stem Count Densities

Source: Undersander and Cosgrove, University of Wisconsin, 1992

When alfalfa is about 15 cm (6 in.) in height, stems/m^2 (stems/ft^2) can be used as the density measure. Stem density of 590 stems/m^2 (55 stems/ft^2) has good yield potential (see Figure 3–5, *Alfalfa Yield Potential at Various Stem Count Densities*, this page). There may be some yield loss with stem counts between 431–539 plants/m^2 (40–50 plants/ft^2).

Consider replacing the stand if there are less than 430 stems/m^2 (40 stems/ft^2) and the crown and root health is poor.

Other considerations for keeping or retiring a forage stand include forage inventories and requirements, alternate forage options, how much grass is left in the stand, rotational requirements and weed pressure.



Cereals

4. Cereals

Cereal crops are an integral part of the cropping system in Ontario, grown on approximately 25% of the arable acreage (~1.5 million acres). Cereals offer many benefits to growers, from excellent profit potential to greatly improved soil structure and manure management options. Cereals respond very well to management — with attention to detail, many growers find cereals to be one of their most profitable crops.

Tillage

Tillage Options

Cereal crops do not respond significantly to tillage. Research comparing the yield response of winter wheat to various tillage options demonstrated no yield advantage among moldboard plowing, minimum tillage and no-till systems (see Table 4–1, *Winter Wheat Yield Response to Tillage Systems*, this page). While yields are not affected greatly by tillage systems, good seed-to-soil contact and soil moisture for germination are essential.

The selection of a tillage system will impact other components in the system. The tillage method chosen must fit with factors such as fertility, insect pressure, disease incidence and weed control for producing high-yielding, profitable crops. Risks associated with more intensive tillage in winter crops include greater frost-heaving potential and increased risk of snow mould. Erosion is a concern with tillage in all crops.

There are several options for seeding cereals that include:

- no-till seeding
- conventional tillage
- frost seeding
- aerial seeding of winter cereals
- broadcast seeding

No-Till Seeding

Most winter wheat is grown using a no-till system. No-till yields are often equal to yields obtained with conventional tillage. No-till drills can follow the combine in the same field, which advances seeding date, therefore increasing yields. No-till planted winter cereals are better able to resist frost heaving, as the plant anchors itself in firmer soil.

Table 4–1. Winter Wheat Yield Response to Tillage Systems

Tillage Systems	Comparative Yield[1]		Comparisons	Economic advantage to reduced tillage
	t/ha	bu/acre		$/acre
Minimum vs moldboard	5.2 vs. 5.1	77.5 vs. 75.4	12	15.31
No-till vs moldboard	4.8 vs. 5.0	71.7 vs 74.9	36	18.85
No-till vs minimum	4.4 vs. 4.3	65.0 vs 64.6	22	7.55

Source: Tillage Ontario Database

[1] Average yields vary because comparisons come from a range of sites.

The success of a no-till system requires consideration of fertilizer management, drill capability and weed control. No-till cereals show more response to seed-placed starter fertilizer, especially phosphorus, compared to conventional tilled crops.

No-till crops grown without starter fertilizer often develop "corn row syndrome" symptoms. Wheat plants growing over old corn rows will be significantly taller and more vigorous than plants growing between the rows. This is primarily due to higher phosphorus availability from the corn starter fertilizer band, even though the corn crop was grown 2 or 3 years prior to the wheat crop. Fields receiving 58 kg/ha of supplemental P_2O_5 (100 lb/acre MAP) overcame the variability in wheat growth. The addition of low rates of P with a liquid starter reduced the corn row effect but did not eliminate it. (Table 4–2, *Corn Row Syndrome*, next page, and Plate 23 on page 282). Winter wheat is one of the most responsive crops to phosphorus fertilization. This is shown in Table 4–3, *Yield Response to Fertilizer Rate*, next page, which summarizes 4 years of comparisons on fields with a large range of fertility levels.

Seed-to-soil contact is critical for moisture uptake. No-till drills must be able to cut through residue and penetrate into hard soil to accurately place seed. Adding seed-firming wheels or plastic "hockey stick" seed firmers will help press the seed into the bottom of the seed trench, which will help increase seed-to-soil contact and improve seed depth uniformity.

Table 4–2. Corn Row Syndrome

	Phosphorus Soil Test	Height cm (in.)	Tissue Phosphorous Levels: % P (DM Basis)	Yield t/ha (bu/acre)
In row	19	107 (42)	0.16	5.13 (76.3)
Between row	9	89 (35)	0.12	4.51 (67.1)

Ontario data, eight locations, OMAFRA.

Weed control is critical in no-till systems. A burndown before planting ensures control of dandelions and other winter annual weeds and should be a standard practice. See OMAFRA Publication 75, *Guide to Weed Control,* for burndown recommendations. To reduce disease incidence, use a fungicide seed treatment. For further information on seed treatments, see the OMAFRA Publication 812, *Field Crop Protection Guide.*

In dry soils, the addition or use of tillage coulters may show some benefit in a no-till system. Slight loosening of dry, hard soils allows for better, more rapid root development and growth. In a wet fall season, light tillage may speed soil drying and allow for planting in better conditions. These limited tillage methods should be used when soil conditions dictate.

Conventional Tillage

Cereals have been grown for generations using the plow, disc and cultivator for seedbed preparation. Many spring cereals are still grown using conventional tillage. While this system works well, erosion concerns, fuel costs, labour costs and limited yield response to tillage continue to shift acres into reduced tillage. The guidelines regarding seed-to-soil contact, planting into moisture and seeding depth accuracy are consistent with the no-till section. The tillage operations replace the herbicide burndown.

Frost Seeding of Spring Cereals

Seeding spring cereals into frost can significantly advance seeding dates and increase yields.

"Frost seeding" refers to no-till seeding cereals into a light frost in early spring. After the snow has melted, and the frost is out of the ground, there are often several cold nights with below-zero temperatures. Seeding into this light frost is possible, as the frost will support the tractor and avoid compaction or rutting. It is not essential to close the seed trench when frost seeding, as the soil will naturally fall in and cover the seed as the frost comes out of the ground. Simply set no-till equipment to make a shallow (2.5-cm or 1-in.) seed trench and firm the seed into the bottom of the trench.

Table 4–3. Yield Response to Fertilizer Rate

Placement	Zero Fertilizer	Seed Placed				Seed Broadcast
Source		6-24-6	Monoammonium Phosphate (MAP)			
P_2O_5 rate: kg/ha (lb/acre)	**0 (0)**	**17.6 (16)**	**29 (26)**	**58 (52)**	**117 (104)**	**117 (104)**
Average yield: t/ha (bu/acre)	5.13 (76.3)	5.39 (80.1)	5.57 (82.8)	5.64 (83.9)	5.58 (83.0)	5.29 (78.7)

Average of 28 sites, 2001 to 2004.

The window of opportunity for this method of seeding is short. **Do not attempt this method of seeding when air temperatures drop below –8°C.** The ground will be frozen hard enough to damage the no-till equipment, and seed will be left on the soil surface with poor results. Best results are generally as the frost is just beginning to firm the soil, about –3 to –4°C, often near midnight. It is critical to stop as soon as frost begins to soften in the morning sun, as thawed soil will stick and plug equipment in as little as 15 m (50 ft.) of travel.

While this narrow window of opportunity may not occur every year, the increase in yield from early planting using this technique can be as much as 25%. Table 4–4, *Frost Seeding vs. Seeding Into Dry Soil of Spring Cereals,* opposite page, shows the yield and quality advantage of frost seeding. Frost seeding of winter cereals in the late fall or early winter has also been successful. However, in these situations it is critical that seed placement is at least 2.5 cm (1 in.) deep, and that yield expectations are realistic.

Aerial Seeding Winter Wheat

Aerial seeding is most successful when seed is flown on before 10% of the soybean leaves have dropped. Soybean leaves will cover seed and help retain moisture for wheat germination.

Results from aerial seeding have been variable. The seed is extremely vulnerable to slug damage. Slugs feed on the germ of the kernel, which can severely thin or destroy the stand, particularly on headlands. The seed will appear to still be on the surface, as if waiting to germinate, but on closer examination, the damage to the kernel becomes evident. Reseeding of headlands after soybean harvest can help overcome this problem.

The shallow root system that develops from aerial-seeded wheat is more prone to heaving injury and wind damage (see *Depth of Seeding,* on page 90). In the spring, wheat plants will be attached to the soil by only one hair root. If this hair root breaks as plants twist with the wind, the plant dies.

Table 4–4. Frost Seeding vs. Seeding Into Dry Soil of Spring Cereals

	Yield t/ha (bu/acre)		Test Weight kg/hL (lb/bu)	
Treatment[1]	**Frost**	**Dry Soil**	**Frost**	**Dry Soil**
Oat	5.3 (140.3)	4.6 (120.6)	46.5 (37.3)	44.6 (35.8)
Spring wheat following soybeans	4.6 (67.7)	3.9 (57.5)	75.9 (60.9)	73.7 (59.1)
Spring wheat following corn	4.1 (60.5)	2.6 (39.4)	74.6 (57.9)	64.8 (52.0)

Johnson, OMAFRA, Thorndale 2006–2007.

[1] Each treatment represents an average of three different populations; 0.8, 1.2 and 1.6 million seeds/acre for oat and 1.2, 1.6 and 2.0 millions seeds/acre for spring wheat.

With these inherent risks, yields from aerial-seeded wheat are often 10% lower than from drilled wheat, (limited on-farm trial data). Therefore, aerial seeding is not a standard practice. Where aerial seeding is attempted, increase the seeding rate to 5.0 million seeds/ha (2 million seeds/acre) to compensate for stand loss.

Broadcast Seeding

Broadcast seeding can greatly speed the planting process. It is important to get good seed-to-soil contact and a uniform seeding rate across the width of the spread pattern and between passes of the spreader.

Using airflow units is an effective way to achieve the uniform spread pattern. Till fields at a shallow depth (7.5-cm or 3-in.) twice, at right angles, then pack the crop to help prevent streaking in the seeding pattern and improve seed-to-soil contact.

This method produces an inconsistent seeding depth. Variable maturity and a 5%–10% reduction in yield are often the result. Increasing seeding rates by 10% will help compensate for the potential variability of broadcast seeding.

Variety Selection

The principles of selecting a winning variety do not vary greatly from crop to crop. Quality factors for specific end-use products and the impact on price and yield are confounding factors with wheat variety selection. Ontario grows more types of wheat than any other region in Northeastern North America. Milling and horse oat markets also have specific quality parameters, as does barley for food or malting purposes.

Standard Variety Selection Criteria

- Select varieties based on local growing conditions and planned end-use. Compare varieties for potential yield, standability, disease tolerance and other agronomic factors. Understanding the limitations of a field or farm will help with variety selection.
- Use all information sources available. Cereal crops have an excellent performance testing system. This information is available in infosheets, produced annually by OMAFRA that can be found on the website at www.ontario.ca/crops or on the Ontario Cereal Crop Committee website at www.gocereals.ca .
- Use long-term data over many locations when comparing variety performance. Varieties that excel under one set of environmental conditions may suffer considerably under the next year's conditions. For example, an oat variety that excels in a year without rust pressure may be the worst performer the year rust hits early. Using long-term, multi-site data will lead to the selection of the best, yield-stable varieties.
- Select two or three of the best available varieties. It is always good management to spread the risk. Selecting different varieties reduces disease potential and spreads the harvest workload.

Harvest Sprout Tolerance

Seed dormancy, or sprouting resistance, varies greatly between varieties. Several genes are responsible for the dormancy factor in wheat. One of the strongest of these genes is linked to the genetic coding for red wheat or the red colouration of the bran. In general, red wheat varieties will not sprout as readily as white wheat varieties, and often hard red wheat varieties will sprout less readily than soft red varieties. As white wheat varieties lack sprout tolerance, growers are advised not to grow more white wheat than they combine in two or three days. Harvest white wheat varieties first, as soon as possible, and dry if necessary. This will ensure crop quality and maximize profitability.

Sprouting tolerance should not be confused with germination of the crop once planted. Seed dormancy is dependent on time, light and temperature. By the time the seed is planted in the fall, enough time has passed, and the dark, cool conditions of the soil will overcome any dormancy. The speed of emergence after planting is entirely related to the seed vigour of the variety and seed lot, and not at all to colour or market class.

Table 4–5. Straw Quantity vs. Straw Quality

	Straw Quantity (most to least)		Straw Quality (best to worst)[1]
1	winter wheat	1	two-row spring barley
2	winter barley	2	six-row spring barley
3	two-row spring barley	3	mixed grain
4	mixed grain	4	spring oat
5	spring oat	5	winter barley
6	six-row spring barley	6	spring wheat
7	spring wheat	7	winter wheat

[1] Straw quality based on livestock bedding preferences.

Winter Hardiness and Cold Tolerance

Winter wheat can tolerate extremely cold temperatures (–23°C) in its most hardy state. Winter barley cannot withstand as severe conditions (–10°C). While the threat of cold temperature injury often exists, Ontario conditions rarely cause plant death, except where icing occurs. Snow offers excellent insulation from cold temperatures, while ice conducts cold directly to the plant. More detailed information on cold tolerance and winter hardiness is available in the University of Saskatchewan *Winter Wheat Production Manual* (Chapter 12, Winter Survival) at www.usask.ca/agriculture/plantsci/winter_cereals/Winter_wheat/.

Factors Unique to Cereal Crops

Straw

In livestock regions, the need and value of straw can be significant. Straw quality is also a factor. Moisture absorbency is a factor for most livestock bedding. Dry loose straw has an approximate density of 40 kg/m^3 (2.5 lb/ft^3), while baled straw has an approximate density of 80 kg/m^3 (5 lb/ft^3) and water absorption of 293–335 L/m^3 (1.8–2.1 Imp. gal/ft^3). The horse industry is only interested in "dust-free" straw. Straw has been one of the driving forces for growers to continue growing barley rather than spring wheat, even though the economics of grain production would favour spring wheat.

In general, two-row barley varieties produce more straw than six-row varieties. Oat straw quantity and quality are good. Wheat straw is less absorbent than oat or barley straw, and there is less straw produced by most spring wheat varieties than by spring barley varieties (see Table 4–5, *Straw Quantity vs. Straw Quality*, this page).

Growers who need and value the straw can also increase its quality by using fungicides to control crop diseases. This is especially important for providing dust-free straw to the horse industry. Consider winter barley for higher yields of barley straw if growing in an area where winter survival is not a problem.

Table 4–6. Straw Nutrients

Nutrient	kg/tonne (lb/tonne) Mean	Minimum	Maximum
Nitrogen	7.0 (15.4)	4.2 (9.2)	10.7 (23.5)
Phosphorus (P_2O_5)	1.6 (3.5)	0.9 (2.0)	3.0 (6.6)
Potassium (K_2O)	8.4 (18.5)	4.0 (8.8)	21.2 (46.8)

Johnson, 2003/2004 and Falk, 2004/2005.

Straw value \$/tonne (P and K only)
= \$/tonne MAP x 0.003 + \$/tonne potash x 0.014
Straw value \$/tonne (N, P, K)
= \$/tonne urea x 0.015 + above
To change value to cents/pound, divide answer by 22.05.

Straw Value

The value of straw is often a hotly debated question. Straw has value from both the nutrients removed and the organic matter addition it will return to the soil. Table 4–6, *Straw Nutrients*, this page, shows the range of nutrients that straw may contain. Straw nutrient concentration can vary greatly, Straw from hard wheat varieties will generally contain less (approximately 2.75 lb/tonne or 1.25 kg/tonne) nitrogen than soft wheat straw (Falk, 2005). Potash concentration varies tremendously in straw, as potash is readily leached from straw by rainfall after maturity. The only accurate way to determine nutrient value is through an analysis.

There is added debate about whether the nitrogen component should be included in the value of straw. The carbon:nitrogen ratio of straw is quite high (80:1), which would require additional nitrogen for breakdown by soil organisms. Thus, many growers do not add nitrogen into the value calculation. Using average nutrient concentrations, straw value can be calculated using the formulas shown in Table 4–6.

The value of the organic matter that straw returns to the soil is much more difficult to calculate. There is no doubt that the organic matter value is extremely significant. Estimates range from at least equal value to the nutrient removal, to estimates that removal of four high-yield straw crops could reduce soil organic matter by 0.1%. This 0.1% organic matter could be capable of holding up to 4.4 cm (1.75 in.) of available water for crop growth. In dry seasons, this amount of water might result in an additional 0.24 t/ha (3.5 bu/acre) of soybeans, or 0.88 t/ha (14 bu/acre) of corn yield. While these are simply mathematical estimates of the organic matter impact, they drive home the point of just how valuable that component can be.

Table 4–7. Characteristics of Various Cereal Market Classes

Market Class	Traits and Uses	Characteristics
Soft white winter wheat	Pastry wheat Low protein High yield	Susceptible to sprouting Do not over-apply nitrogen
Soft red winter wheat	Pastry wheat Low protein High yield	Do not over-apply nitrogen
Non-pastry red winter wheat (Hard red winter wheat)	Bread blend wheat, crackers, pizza dough High protein desirable Lower yielding than the soft wheat	Requires more nitrogen Quality more variable Price premiums may apply
Non-pastry white winter wheat (Hard white winter wheat)	Whole grain flour products Asian noodles	Susceptible to sprouting Requires more nitrogen Class just developing (2008)
Specialty winter wheat varieties	Variable	Must be maintained and identified by variety
Spring milling wheat varieties	Bread blend wheat High protein Low yield	Responds best to early planting High price
Spring feed wheat varieties	High protein Moderate yield	Responds best to early planting Must not be co-mingled with milling wheat
Winter barley	High yield Poor winter hardiness Poor standability	Plant early Difficult to remove awns during threshing
Six-row barley	Good straw More heat tolerant More tolerant of late planting	Less desirable grain sample Do not over-apply nitrogen
Two-row spring barley	Milling and malting types available Excellent straw Good straw volume	Do not over-apply nitrogen
Oat	Milling and horse oat require high quality Good straw	Responds well to early planting Tolerates poor drainage

Market Class

Within wheat, the number of market classes continues to increase (see Table 4–7, *Characteristics of Various Cereal Market Classes*, this page). Since the mid-1980s, when only spring feed wheat and soft white winter wheat were grown in Ontario, the number of market classes has expanded dramatically. This increase in wheat classes is likely to continue, with varieties for other specific market uses in development. Many of these market classes have yield and price premium implications that must be considered when selecting varieties. For example, high protein, non-pastry wheat varieties generally have a yield penalty (approximately 10%) associated with achieving higher protein. However, these varieties have a price premium. It is much easier to achieve high protein and earn premiums on farms with more inherent soil nitrogen (i.e., livestock farms with manure and/or forages). On cash crop farms, it often takes significantly more nitrogen to achieve optimum protein levels in these non-pastry wheat varieties (see *Red Winter Wheats*, on page 98). All these factors must be considered when selecting varieties.

Cereal Species

Barley

All barley has the genetic potential to develop six rows of grain in the head (six-rowed barley). Two-rowed barley only develops two of these rows. In general, two-rowed varieties are larger seeded, shorter and more resistant to lodging, leaf rust and mildew. Two-rowed varieties often mature later and have lower yields than six-rowed types. Six-rowed varieties usually have better resistance to scald and are more tolerant of heat and moisture stress, making them more tolerant of late planting. The more open canopy of six-rowed types makes them less competitive for underseedings, while the lodging resistance of two-rowed types must be taken into account when underseeding.

Winter Barley

Both spring and winter types of barley are grown in Ontario. Winter barley requires a period of cold temperatures to "vernalize" the plant and initiate flowering and grain development. Winter barley planted in the spring will not produce grain. Spring barley does not require this vernalization process.

Winter barley is much higher yielding than spring barley but is considerably less winter hardy than winter wheat. It survives only in areas with milder winter conditions or excellent snow cover. Winter barley must be planted earlier than winter wheat, making it more prone to barley yellow dwarf virus (BYDV) and snow mould. Winter barley matures earlier than winter wheat, and some years may be suitable for double cropping. In areas that are adapted to winter barley production, yields of up to 8.1 t/ha (150 bu/acre) have been achieved.

Hulless Barley

Covered or hulled barley consists of approximately 10% hull and 90% kernel. With hulless types, much of the hull is removed at harvest. Hulless barley has a higher test weight and lower fibre content than covered barley. The seeds must be handled carefully, as the embryo (germ) is susceptible to damage. The amount of hull removed from the grain is somewhat dependent on weather conditions at harvest. Hulless barley will yield less than regular varieties, because the weight of the hulls is left in the field, but the concentration of energy and protein will be greater.

Oat

Oat is a traditional feed crop in Ontario, particularly for horses. Oat has better balanced protein and higher fibre content than barley. Grow leaf rust-resistant varieties. Buckthorn acts as the alternate host for leaf rust in oat. Remove buckthorn from field margins whenever possible.

Milling Oat

Milling oat is used for human consumption and therefore must meet special quality requirements, including plump kernels, high test weight and groats (grain) that are free of discolouration and foreign material (insects, weeds or other crop seeds). Requirements for milling oat can be found at www.grainscanada.gc.ca/ (click on "Grain Quality," to find the *Official Grain Grading Guide*, under "Guides and Manuals").

Hulless Oat

Hulless oat may be of interest to pig and poultry producers because the grain (groat) is approximately the same metabolizable energy content as corn. They have good quality protein and high protein content (14%–20%). Diets can be formulated with hulless oat as a major energy source and only small amounts of soybean meal, canola meal or the amino acid lysine need be added to obtain performance comparable to a standard corn-soybean meal diet.

Hulless oat becomes groats when they are threshed. The thin hulls are left in the field as chaff, resulting in a kernel weight loss of 25%–30% compared to regular varieties where the hull is retained. Current varieties have a coating of fine hair on the groat that prevents the oat from flowing freely. These hairs cause itching, making the oat unpleasant to handle. Recent variety introductions have greatly improved on these issues.

Pay special attention to planting, harvesting, handling and storage of hulless oat. Since the hull does not protect the seed, germination is easily reduced. Take care during the planting process. Embryo damage can occur during harvest and handling. The high oil content at the surface of the seed makes the seed more attractive to storage insects. Moistures should be below 10% to ensure the grain does not go "off quality" in storage.

Mixed Grains

Mixed grains occupy a significant acreage in the province. Most mixed grains are a combination of oat and barley, but mixtures may include spring wheat or field peas. Mixed grains are only grown for feed.

No specific recommendations regarding the best mixtures can be made. Generally, the highest yielding varieties of oat and barley in pure stands also perform best in mixtures, but maturity ratings of the components of a mixture must be matched. The addition of wheat or peas to the mix will increase the energy or protein of the grain, but yields will be reduced.

Leaf and head diseases are usually much less severe with mixed grains than where oat or barley is grown alone. Mixtures of oat and barley are more tolerant of variable drainage conditions, with the barley component becoming predominant in drier areas of the field and the oat component producing more in poorly drained areas.

Winter Wheat

Winter wheat is grown on the largest acreage of any of the cereal crops and is grown across most of the province. Like winter barley and winter rye, winter wheat requires vernalization, a period of cold temperature (0°C–5°C), that induces the crop to shift from a vegetative to a reproductive state. While wheat vernalizes most effectively at the five-leaf stage, the vernalization process can be completed once germination begins. Therefore winter wheat can be planted at any time in the fall, right until freeze-up, and still head out normally the following year. Winter wheat planted in the spring will not enter the reproductive stage, as it has not been vernalized. In some cases, winter wheat has been spring planted to give the appearance of a lawn that almost never needs cutting.

Spring Wheat

Feed Wheat

Feed wheat is a more concentrated source of protein and energy for livestock than barley or oat. In non-ruminant diets, take care to limit the amount of feed wheat in the ration to avoid digestive problems. The general guideline is to include no more than 25% of the total ration as wheat. Be sure to consult a nutritionist for further information.

Some feed wheat varieties can produce yields that are competitive with oat and barley as feed grain. At times, these varieties may achieve quality that allows them to be included in the milling wheat market. Check with your seed supplier or the Ontario Wheat Producers Marketing Board to determine if a variety is generally of milling or feed quality. When feed wheat varieties do make milling quality, consider it a bonus and not something to depend on.

Milling Wheat

To ensure market acceptance, take care to grow a quality product. This includes factors such as selecting the proper variety, early planting and good weed control. Spring wheat varieties generally have a very open canopy, making weed control more critical. This open canopy makes them ideal as a nurse crop for underseeded alfalfa or hay crops.

Rye

Both spring and winter types of rye are available and grown in Ontario. Typically, winter rye is grown on the light sandy soils of tobacco and vegetable farms to control wind erosion and build up organic matter. Spring rye is occasionally grown as an annual forage crop. Unlike the other cereal crops, rye is quite susceptible to ergot, which is detrimental to its use as either feed or food.

Winter rye is the most winter hardy of all the winter cereals. It is extremely early maturing — well ahead of either winter wheat or winter barley. Rye is hard to thresh, and despite the early maturity is not harvested until well after wheat and barley crops. This allows the straw to degrade and facilitates the threshing of the grain from the head.

Some producers looking for extra forage have started to plant winter rye after the corn is harvested. This rye will begin to head about mid-May the following spring, when it is cut for baleage or haylage. Soybeans or dry edible beans are then planted with almost no yield loss due to delayed planting. Concerns from this practice include potential allelopathic effects (the toxic effects of rye residue breakdown during new crop growth) from the rye residue and the possibility of volunteer rye in wheat crops in succeeding years.

Triticale and Spelt

Both triticale and spelt are grown in Ontario on a limited basis. Triticale, a cross between wheat and rye, is only grown as emergency forage when hay crops winterkill, mostly in combination with peas (see *Warm-Season Annual Grasses*, on page 56). Spelt, an earlier version of modern day wheat, is mostly grown organically for that market. There is almost no genetic difference between spelt and wheat, just the genetic coding for the "chaff" to either adhere to the grain or be easily removed. In wheat, the chaff comes away easily, while in spelt it does not.

Biotechnology

Most crop plants are diploids, meaning that they have one pair of each chromosome. Both barley and oat are diploids. Durum wheat is a tetraploid: having two pairs of chromosomes. All other wheats grown in Ontario are hexaploid, with three pairs of chromosomes. This makes gene transfer in wheat somewhat more difficult. The profit margin in cereals for seed production and breeding is much less than in many other crops. Additionally, the acceptance of genetically modified wheat plants by consumers has been very low, resulting in less investment in biotechnology in wheat. Thus, cereal crops have been at a standstill in the development of varieties having special traits using gene transfer technology.

This situation appears ready to change. How the industry and consumer will respond to these changes has yet to evolve. Growers should be aware of these developments and the criteria for identity preservation and separation that may go along with any new developments.

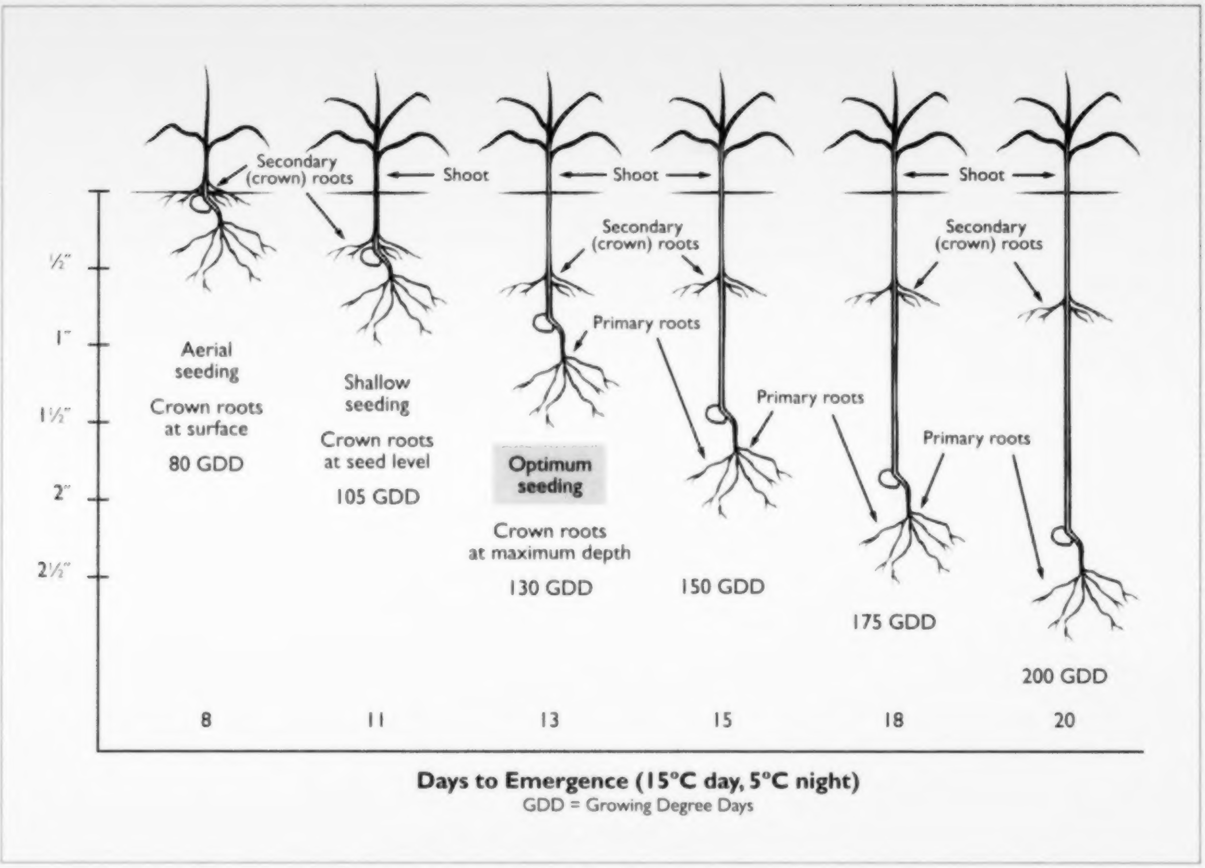

Secondary (crown) roots
Shoot
Shoot
Shoot
Secondary (crown) roots
Secondary (crown) roots
Primary roots
Primary roots
Primary roots
Primary roots
½"
1"
1½"
2"
2½"
Aerial seeding
Crown roots at surface
80 GDD
Shallow seeding
Crown roots at seed level
105 GDD
Optimum seeding
Crown roots at maximum depth
130 GDD
150 GDD
175 GDD
200 GDD
8
11
13
15
18
20
Days to Emergence (15°C day, 5°C night)
GDD = Growing Degree Days

Figure 4–1. Days to Emergence at Various Seeding Depths

Planting and Crop Development

Depth of Seeding

Seeding depth can have a significant impact on plant development (see Figure 4–1, *Days to Emergence at Various Seeding Depths*, this page), but soil conditions at the time of planting must always dictate seeding depth. Do not plant shallow into dry soil in anticipation of rain for germination. Plant into moisture to ensure quick and uniform emergence, even if deep planting is required. However, when soil conditions are too wet, consider shallow planting or making an additional tillage pass in an attempt to dry the soil.

Cereals are lagging far behind corn and soybeans in the development and adoption of technology to accurately control seeding depth. With current drills, seed depth can vary from 1.25–7.5 cm (½–3 in.) in the same row, depending on soil conditions.

Growers can attempt to minimize this variation in depth by using seed firmers, which hold the seed at the bottom of the trench. Level fields and slower planting speeds will help reduce variability. Seeding depth accuracy in cereals will not match corn as long as depth gauge wheels (press wheels) trail double disc openers, or single coulters without parallel linkage are standard equipment.

Cereals are the most responsive crops to early, timely seeding (see *Planting Dates*, on page 92). When cereals are seeded too deep, delayed emergence of 1 week or more may occur (see Figure 4–1, this page). Delayed emergence is equivalent to an equal delay in seeding date, resulting in an equal reduction in yield. It is evident that the accuracy of seeding equipment requires improvement.

At typical fall temperatures of 15°C days and 5°C nights (15°C + 5°C = 20/2 = 10 GDD/day), 8 days would be required for germination and an additional 5 days for each inch of planting depth to reach emergence. Cooler temperatures will slow this process.

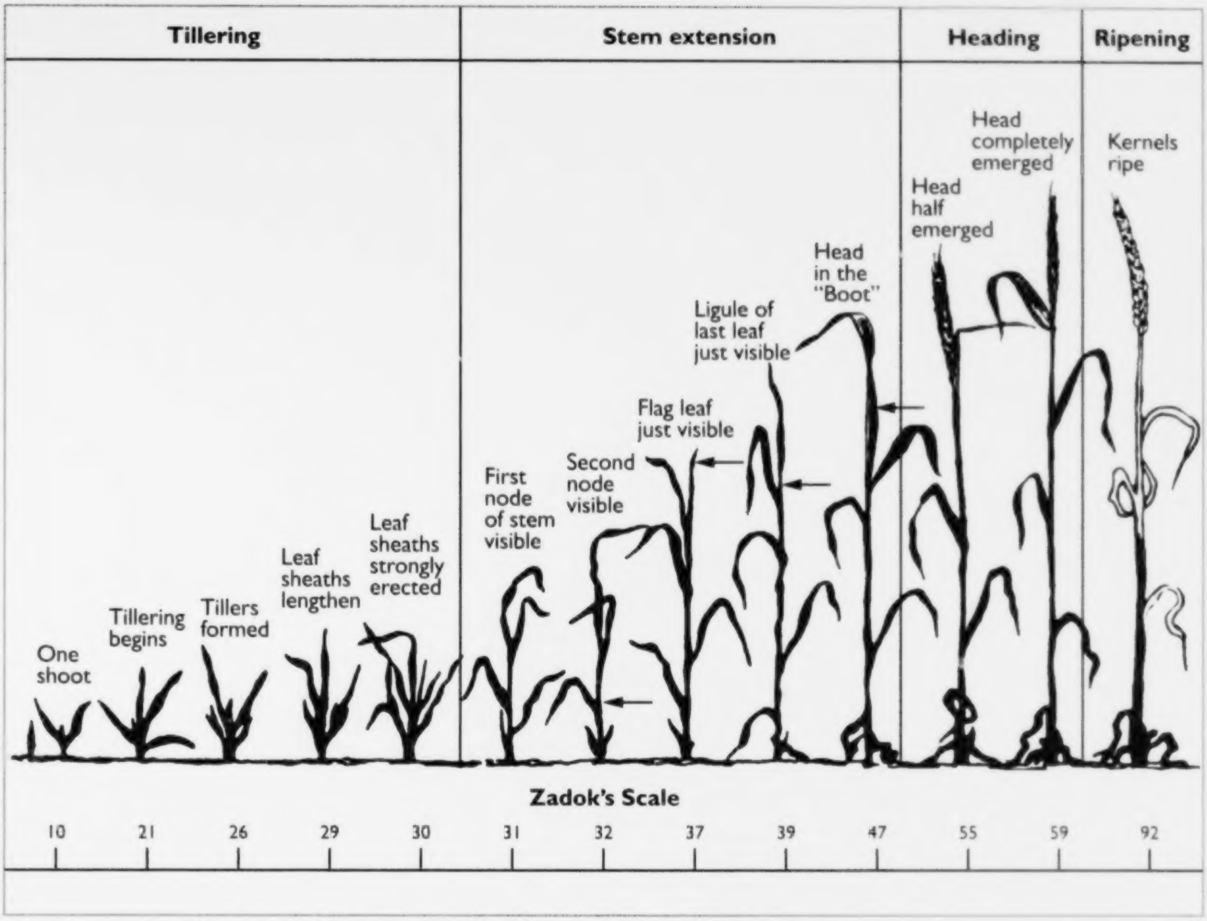

Tillering
Stem extension
Heading
Ripening
One shoot
Tillering begins
Tillers formed
Leaf sheaths lengthen
Leaf sheaths strongly erected
First node of stem visible
Second node visible
Flag leaf just visible
Ligule of last leaf just visible
Head in the "Boot"
Head half emerged
Head completely emerged
Kernels ripe
Zadok's Scale
10
21
26
29
30
31
32
37
39
47
55
59
92

Figure 4–2. Cereal Growth Stages

Optimum Seeding Depth

Cereals should be planted uniformly at a depth of 2.5 cm (1 in.). This encourages early emergence and rapid development of an extensive secondary root system. Moisture availability is an overriding factor, and seed must be placed into moisture. A 2.5-cm (1-in.) planting depth is of little value if moisture is not available at this depth.

Growers that do an accurate job of seeding winter wheat will experience better winter survival and higher yields.

Cereal Development

The development of the cereal seedling can be determined by following growing degree day (GDD) accumulations. GDD calculations are discussed in greater detail in *Growing Degree Days*, on page 180. For cereal crops, use GDD base 0 calculations.

Generally, cereals require 80 GDDs for the seed to germinate and 50 additional GDDs for emergence, for each inch of planting depth.

For more detailed information and identification of cereal growth stages, see the *Cereal Staging Guide* at www.bayercropscience.ca website (under Tools and Guides).

Figure 4–2, *Cereal Growth Stages*, this page, shows the cereal crop development according to the "Zadok's Scale" ("Feekes" is another cereal development scale not shown here). These stages are critical in many management decisions that growers make. Nitrogen and herbicide applications must be completed during the tillering stage; disease control is most critical in the stem extension and heading stage. Knowing the growth stage of the crop is essential to accurately schedule management inputs and control measures.

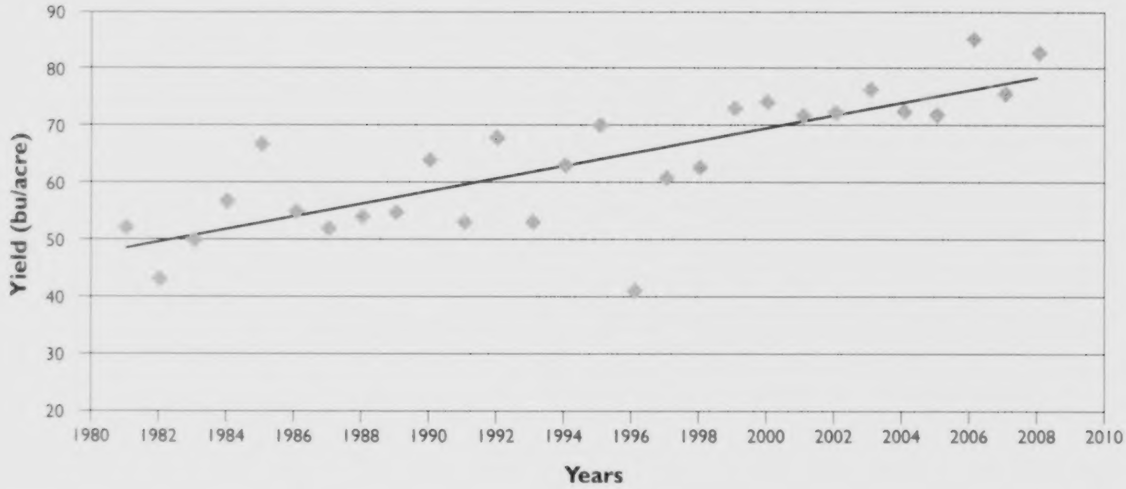


Figure 4–3. Provincial Winter Wheat Yield for 1981–2008

Planting Dates

Cereal crops are even more responsive to planting date than corn. Ontario research shows a 0.07 t/ha/day (1.1 bu/acre/day) decrease in yield for each day that cereal planting is delayed beyond the optimum date.

Provincial winter wheat yields from 1981 to 2008 are illustrated in Figure 4–3, *Provincial Winter Wheat Yield for 1981–2008*, this page. Record yields in 2006 and 2008 were primarily due to early planting the previous fall, while low yields in 1993 were the result of late seeding in the fall of 1992. The low yield of 1996 was caused by a severe fusarium infection.

Early Planting

Winter cereals can be seeded too early. Seeding more than 10 days before the optimum date introduces risk from Hessian fly, snow mould, and barley yellow dwarf virus (BYDV) infection. BYDV is spread by aphids, which feed on wheat seedlings. Seed-applied insecticides can minimize the risk of spread of BYDV but will not eliminate the risk. Check varietal response to BYDV in the performance trials at www.gocereals.ca. Aphids are very susceptible to low temperatures. Aphid numbers and related concerns drop off as cool fall temperatures arrive. (For more information on Hessian fly, cereal aphids or BYDV, see Chapter 13, *Insects and Pests of Field Crops*, and Chapter 14, *Diseases of Field Crops*).

While seeding of winter cereals can be too early, the risk of not planting in a timely fashion carries great yield risk for growers on heavy, poorly drained clay soils. In these situations, plant if the soil conditions are fit. When seeding more than 10 days prior to the optimum date, decrease the seeding rate by 25%. Using lower seeding rates in this situation reduces the risk of snow mould and lodging potential. Yields often increase with lower seeding rates at these early planting dates.

As winter barley must be seeded early, select a variety with tolerance to BYDV, or utilize seed-applied insecticides that control aphids. See Publication 812, *Field Crop Protection Guide*.

Spring Cereals

It is virtually impossible to seed spring cereals too early, unless soil conditions are excessively wet. This tremendous response to early seeding is convincing some producers to consider frost seeding. Cool, moist spring conditions promote tillering and production of large heads. The flowering dates of the crop are also advanced, avoiding the hot, dry conditions that often exist in late June and July.

The target date for planting spring cereals is April 10 for Southwestern Ontario, April 15 for Central and Eastern Ontario and May 10 for Northern Ontario. In areas of greater than 3,100 CHUs, spring cereals are generally not recommended and should definitely not be grown if planting is delayed beyond April 20.

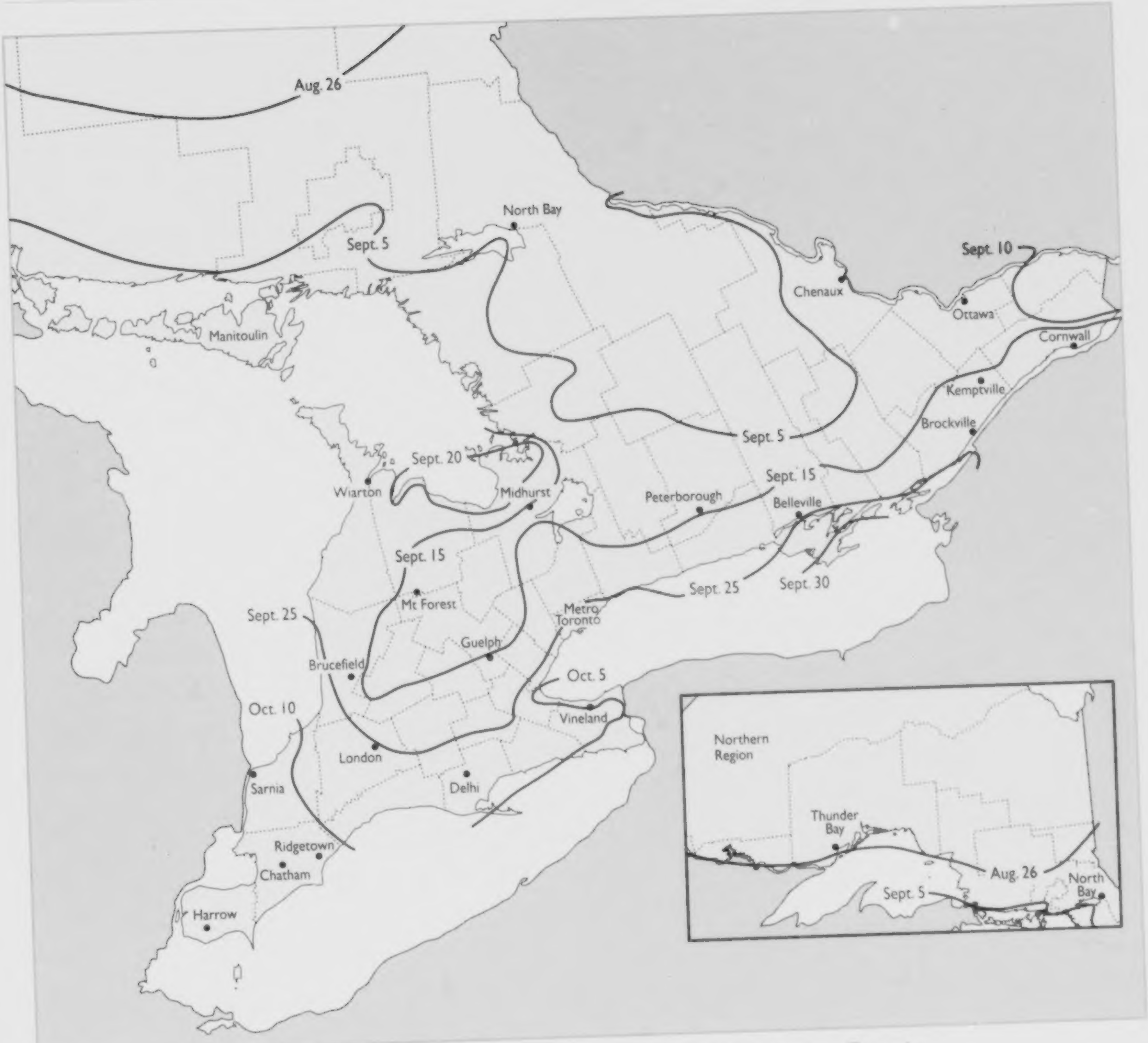

Aug. 26
North Bay
Sept. 5
Sept. 10
Chenaux
Ottawa
Cornwall
Manitoulin
Kemptville
Brockville
Sept. 5
Sept. 20
Sept. 15
Wiarton
Midhurst
Peterborough
Belleville
Sept. 15
Mt Forest
Sept. 25
Sept. 30
Sept. 25
Metro Toronto
Guelph
Brucefield
Oct. 5
Oct. 10
Vineland
London
Delhi
Sarnia
Ridgetown
Chatham
Harrow
Northern Region
Thunder Bay
Aug. 26
Sept. 5
North Bay

Figure 4–4. Optimum Date to Seed Winter Wheat Across Ontario

Winter Cereals

The seeding date for winter wheat is often determined by the date soybeans are harvested. This can delay optimal planting dates for winter wheat, resulting in reduced yields. Wheat grown after soybeans is easily facilitated by following the simple guidelines outlined in *Winter Wheat Following Soybeans*, on page 33.

Figure 4–4, *Optimum Date to Seed Winter Wheat Across Ontario*, this page, shows the optimum seeding dates for winter wheat. The isolines on the map are based on average weather conditions; actual results will vary from year to year. Seed winter barley 7–10 days prior to the optimum dates for winter wheat to improve winter survival. Winter barley has less winter hardiness than winter wheat.

Replanting

Winter cereals are one of the few crops that provide a second opportunity to assess the crop in spring and replant to another crop if winter survival was not acceptable. Assess the wheat crop during April and early May. Leave the replant decision as late as possible to accurately determine plant stand and plant health.

Table 4–8. Determining Yield Potential for Various Plant Stand Counts

Number of Plants			Planting Date	
			Yield t/ha (bu/acre)	
per metre of row	per foot of row	% Yield Potential	Oct. 5	Oct. 15
66	20[1]	100	5.34 (80)	4.84 (72)
33	10	95	5.11 (76)	4.57 (68)
23	7	90[2]	4.84 (72)	4.37 (65)
20	6	85	4.57 (68)	4.10 (61)
16	5	80	4.30 (64)	3.90 (58)

Source: Smid, Ridgetown College, University of Guelph, 1986–90.

[1] Full stand.

[2] 23 plants/m (7 plants/ft) of row, healthy and evenly distributed, will still achieve 90% of yield potential and does not require replanting. A field with an average of 23 plants/m (7 plants/ft) of row without relatively uniform distribution, or with plants severely damaged by heaving and other injury factors, will not yield satisfactorily. Consider replanting in this case.

Damaged plants will often recover under good weather conditions, while plants that are expected to recover may die if hot dry conditions exist. Table 4–8, *Determining Yield Potential for Various Plant Stand Counts*, this page, indicates yield potential for various plant stand counts. The planting date will have an impact on the replant decision.

Seeding Rates

Historically, the seeding rates of cereal crops were recommended in bu/acre, with 2 bu/acre a standard that covered most cereal crops.

Blanket statements of this nature are no longer acceptable. Seed size affects seeding rate. Set optimum seeding rates for each cereal crop. Table 4–9, *Recommended Plant Populations for Cereal Crops*, this page, gives the recommended seeding rates for each crop. Table 4–10, *Determining Seeding Rate*, opposite page, indicates the seeds per metre of row and kilograms of seed per hectare required to achieve various desired plant populations.

In terms of seeding rates and desired plant populations, a variety with fewer seeds/kg will be at a disadvantage to a variety with more seeds/kg. To achieve the recommended rate for most soils, a higher seeding rate (kg/ha) will be required for varieties with few seeds/kg.

Table 4–9. Recommended Plant Populations for Cereal Crops

	Target Plant Population		
Crop	Plants/m² (plants/ft²)	Seeds/ha (x1,000)	Seeds/acre (x1,000)
Barley	250–350 (23–33)	2,500–3,500	1,000–1,400
Oat	200–300 (19–28)	2,000–3,000	800–1,200
Mixed grain	200–350 (19–33)	2,000–3,500	800–1,400
Spring wheat	300–400 (28–37)	3,000–4,000	1,200–1,600
Winter wheat	350–450 (33–42)	3,500–4,500	1,400–1,800

Use the higher rates in Table 4–9 and Table 4–10:

- where emergence and early seedling establishment are likely to be poor (for example, due to poor seedbed and aerial or broadcast seedings)
- for late planting where tillering will be reduced
- on very heavy clay soils

The seeding rate can be determined using this formula:

$$\text{Seeding rate (kg/ha)} = \frac{\text{seeds/ha}}{\text{seeds/kg}} \times \frac{100}{\text{\% germination}}$$

$$\text{Seeding rate (lb/acre)} = \frac{\text{seeds/acre}}{\text{seeds/kg}} \times \frac{100}{\text{\% germination}}$$

Sample Calculation

Seeds/kg (seeds/lb) should be stated on the seed tag or bag. For instance, if 3.7 million seeds/ha (1.5 million seeds/acre) is desired, with a germination rate of 95% and 26,500 seeds/kg (12,000 seeds/lb), the seeding rate would be 147 kg/ha (132 lb/acre).

$$\text{Metric} = \frac{3{,}700{,}000}{26{,}500} \times \frac{100}{95} = 147 \text{ kg/ha}$$

$$\text{Imperial} = \frac{1{,}500{,}000}{12{,}000} \times \frac{100}{95} = 132 \text{ lb/acre}$$

Table 4–10. Determining Seeding Rate

	Desired Plant Population **seeds/ha x 1,000 (seeds/acre x 1,000)**					
	2,000 **(809)**	**2,500** **(1,012)**	**3,000** **(1,213)**	**3,500** **(1,416)**	**4,000** **(1,619)**	**4,500** **(1,661)**
Row Width	**Seeds per Metre of Row (seeds per foot of row)**					
25 cm 10 in.	49 (15)	62 (19)	75 (23)	89 (27)	102 (31)	112 (34)
20 cm 8 in.	39 (12)	49 (15)	62 (19)	69 (21)	82 (25)	92 (28)
19 cm 7.5 in.	38 (12)	46 (14)	56 (17)	66 (20)	75 (23)	85 (26)
18 cm 7 in.	36 (11)	43 (13)	52 (16)	62 (19)	69 (21)	79 (24)
15 cm 6 in.	30 (9)	39 (12)	46 (14)	52 (16)	59 (18)	69 (21)
10 cm 4 in.	20 (6)	26 (8)	30 (9)	36 (11)	39 (12)	46 (14)
Seeds/kg (seeds/lb)	**Kilograms of Seed per Hectare (lb of seed per acre)**					
22,100 (10,000)	90 (80)	112 (100)	134 (120)	157 (140)	179 (160)	202 (180)
24,300 (11,000)	82 (73)	102 (91)	122 (109)	142 (127)	162 (145)	184 (164)
26,500 (12,000)	75 (67)	93 (83)	112 (100)	131 (117)	149 (133)	168 (150)
28,700 (13,000)	69 (62)	86 (77)	103 (92)	121 (108)	138 (123)	155 (138)
30,900 (14,000)	64 (55)	80 (71)	96 (86)	112 (100)	128 (114)	144 (128)
33,200 (15,000)	59 (53)	75 (67)	90 (80)	104 (93)	120 (107)	134 (120)
35,400 (16,000)	56 (50)	71 (63)	84 (75)	99 (88)	112 (100)	127 (113)
37,600 (17,000)	53 (47)	66 (59)	80 (71)	92 (82)	105 (94)	119 (106)
39,800 (18,000)	49 (44)	62 (55)	75 (67)	87 (78)	100 (89)	112 (100)
42,000 (19,000)	47 (42)	59 (53)	71 (63)	83 (74)	94 (84)	106 (95)
44,200 (20,000)	45 (40)	56 (50)	67 (60)	78 (70)	90 (80)	101 (90)

Table 4–11. Winter Wheat Row Widths

	Winter Wheat Row Spacing				
	10 cm (4 in.)	**18 cm (7–7.5 in.)**	**25 cm (10 in.)**	**36 cm (14–15 in.)**	**51 cm (20 in.)**
Location	**Yield t/ha (bu/acre)**				
U.S					
Wisconsin 1985–87	6.32 (94)	6.32 (94)	5.44 (81)	–	–
Ohio	–	4.10 (61)	4.03 (60)	3.97 (59)	3.56 (53)
Canada					
Ontario[1]	5.38 (80)	5.38 (80)	–	–	–
Ontario[2]		88.8		81.4	
On-Farm Trials					
Essex County	–	5.12 (76)	4.97 (74)	–	–
Middlesex County	–	5.98 (89)	5.91 (88)	–	–

[1] Source: Smid, Ridgetown College, University of Guelph, 1987–90.

[2] Johnson, 2006/2007 Cord report.

Row Widths

Considerable research has been conducted on cereal row widths for maximum yield. Table 4–11, *Winter Wheat Row Widths*, this page, summarizes some winter wheat row width research from across Ontario and the northern U.S. On-farm results from Ontario are included. There is no evidence to support narrowing row widths below the standard 18–19 cm (7–7.5 in.) spacing for winter crops.

There appears to be a yield penalty with wider rows. The most recent Ontario row-width research shows an 8% decrease in yield when moving to 38 cm (15 in.) rows from 19 cm (7.5 in.). In some cases, this yield loss may be offset by reduced equipment costs and result in more profit if less equipment investment is required. Many of the new 25-cm (10-in.) row planters have more accurate seed placement than 19-cm (7.5-in.) drills. With the importance of seeding depth, this improved accuracy may partially overcome the row width impact, as indicated by the Essex, Middlesex and Ohio data, where accurate planting equipment was used for the 25-cm (10-in.) row widths.

For spring cereal crops, trials in Northern Ontario have shown yield increases of more than 5% when row width was reduced from 18-cm to 10-cm (7-in. to 4-in.) spacing. Moving to 10-cm (4-in.) rows in this production area may prove beneficial. However, it is difficult to achieve these narrow row widths in a no-till system.

Table 4–12. Management Considerations for Wheat Following Various Crops in Rotation

Following:	Comments
Beans (soybeans or dry edible beans)	• Excellent rotation • When soybean harvest is delayed, wheat planted later will have lower yield potential. • On sandy soils, European chafer populations can reduce plant stands.
Canola	• Excellent rotation • Best option for timely planting • Response to starter P may be greater.
Corn (silage or grain)	• Highest risk of fusarium • Timely planting is possible. • For wheat after corn, plant a variety that is MR for fusarium (see www.gocereals.ca) and plan to apply a fungicide to prevent fusarium.
Alfalfa (pure stands)	• Timely planting is possible. • Insect damage is a concern. • Nitrogen credit is not fully utilized because of timing of N release relative to crop requirements. Up to half the N is released after crop uptake is complete.
Grass hay	• Poor rotation • Primary risk is take-all, a root disease that infects the crop in the fall with a potential yield loss of over 50%, and other root diseases. • Later planting combined with seed-placed potash fertilizer provides some take-all suppression.
Oat	• Reasonable rotation. Few diseases cross over between wheat and oat.
Barley	• Not a desired rotation • Many of the root diseases cross over between barley and wheat. • Later planting combined with seed-placed potash fertilizer provides some take-all suppression.
Wheat	• Worst rotation choice (not a rotation) • Leaf disease and root disease pressure will be at its maximum. • Take-all, eyespot and cephalosporium stripe are at high risk with little or no management options. • Expect a minimum 10% yield loss.

Crop Rotation for Winter Wheat

Crop rotation is an integral part of any production system. The greatest benefit to a good crop rotation is increased yields. A well-planned crop rotation will help with insect and disease control and aid in maintaining or improving soil structure and organic matter levels. In addition to increasing yields, using a variety of crops can reduce weed pressures, spread the workload, protect against soil erosion and reduce risk. Table 4–12, *Management Considerations for Wheat Following Various Crops in Rotation*, this page, shows some of the risks associated with, and management options for, wheat following other crops.

Additional Management Opportunities

Fungicides and Growth Regulators

Growers familiar with European cereal production are aware of the yield increases possible with the use of fungicides, growth regulators and increased fertility. Under Ontario conditions, it is more challenging to realize profits from incorporating these additional inputs within the production system. Experienced growers with high management capabilities in cereal production have developed the ability to use and profit from these strategies. Growers must be able to determine the best timing for application, as well as whether it is warranted.

Foliar disease control is one of these management strategies. Further information on disease identification and control can be found in Chapter 14, *Diseases of Field Crops*, and in OMAFRA Publication 812, *Field Crop Protection Guide*. Thresholds for disease control vary, depending on the disease present, the stage of growth and condition of the crop. In general, it is important to scout the top two leaves of the cereal crop, at any stage of growth. If disease is moving onto one or both of these leaves, determine if the control threshold control has been reached and if control is warranted.

Growth regulators are another management option to consider. Some cereal varieties have excellent yield potential but lodge prior to harvest, reducing yield and quality. Growth regulators, when used at the proper application time and rate, can shorten and strengthen the straw and maintain standability until harvest. Varieties with excellent lodging resistance (see www.gocereals.ca) do not require this additional input.

Spraying Basics: Fusarium Control in Wheat

Application of fusarium control fungicides requires specialized nozzles or nozzle combinations to achieve optimum results. Maximizing wheat head coverage requires both proper timing and the best nozzle configurations.

Maximize Spray Coverage of Wheat Heads

The key to applying fungicides to prevent fusarium head blight (FHB) is to spray all sides of all wheat heads with product. Heads that are missed or only partially sprayed are not protected adequately. Research carried out at the University of Guelph's Ridgetown Campus since 2001 has evaluated spray nozzles and nozzle combinations to maximize spray coverage on all sides of the wheat heads.

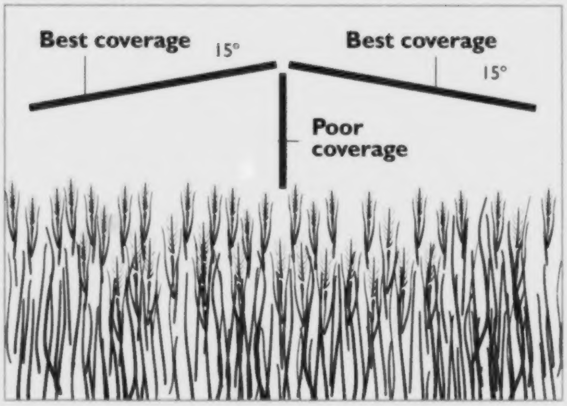


Figure 4–5. Recommended Nozzle Orientation of a Forward-and-Back Double Nozzle Assembly

Nozzles with a shallow attack angle, such as forward-and-back double nozzles and alternating turbo floodjets, have significantly better spray coverage of wheat heads than nozzles spraying straight down.

Results showed that the closer the nozzles sprayed to horizontal, in a forward and back manner, the better the spray coverage. Nozzles that spray close to vertical had significantly less spray coverage on the heads. Figure 4–5, *Recommended Nozzle Orientation of a Forward-and-Back Double Nozzle Assembly*, this page, shows a boom-end view of the recommended nozzle orientation of a forward-and-back double nozzle assembly. Turbo FloodJet nozzles alternating forward and back every 20 in. along the boom also have this 15°-below-horizontal spray inclination. These two nozzle set-ups provide the best spray coverage for FHB control.

Water Volumes

Follow label directions. More water should improve spray coverage, especially in windier conditions. For ground application keep water volumes in the 18–20 gallons/acre (GPA) range. Do not exceed 20 GPA application rates.

Spraying Speed

Spray coverage levels are very near equal from 10–20 km/h. In research trials, travel speed did not change the ranking or coverage level of the different nozzles. Spraying speed is not a critical factor in spray coverage of wheat heads.

Nozzle-to-Target Distance

Forward-and-back double nozzle assemblies and alternating Turbo FloodJets should be operated at 25–30 cm (10–12 in.) above the wheat canopy. Operate other nozzles a sufficient height above the canopy — about 50 cm (20 in.) — to allow full pattern development. Operating nozzles higher than this minimum nozzle-to-target distance will result in a significant reduction in spray coverage. Operating the boom at double the minimum nozzle-to-target distance from the wheat heads could reduce head coverage by as much as 50%.

Application Timing for Fungicides for FHB Control

Day 0 occurs when 75% of the heads on the main stems are fully emerged. Target spray applications for Day 1 to Day 4, with optimum timing of Day 2.

Rain Fastness

Current FHB fungicides (Folicur and Proline) are both rainfast in 1 hour. Spray once wheat heads are fairly dry. Moisture droplets on the heads may cause spray to run off, thereby reducing coverage levels.

Sprayer Cleanout Before Spraying Wheat

It is essential to clean out sprayers totally, including boom end caps. Wheat at heading is incredibly sensitive to any tank contamination, with yield loss approaching 100% in severe cases. If sprayer cleanout is not adequate, growers would be better not to spray for FHB.

Fusarium Forecasting

Weather INnovations Inc (WIN) offers the DONcast forecast modelling system. This free service has been made possible by sponsorship from the Ontario Wheat Producers' Marketing Board and Bayer CropScience. Visit the WIN website at www.weatherinnovations.com and follow the prompts.

Fertility Management

Nitrogen

Cereals are members of the grass family and are very responsive to nitrogen. Over-application of nitrogen causes lodging in cereal crops, resulting in reduced yield, quality and harvestability (Plate 24 on page 282). The optimum rate of nitrogen for a particular field will depend on the crop being grown, past applications of manure or fertilizer to the field, soil type and crop rotation. Use general recommendations as a starting point but combine them with observations of crop growth and lodging tendency.

Table 4–13. Nitrogen Requirements for Cereal Crops

Crop	N Required[1] kg/ha	N Required[1] (lb/acre)
Barley (areas receiving 2,800 CHUs or less)	70[2]	(63)
Barley (areas receiving < 2,800 CHUs)	45	(40)
Cereals seeded as a nurse crop for forages	15	(14)
Mixed grain, spring triticale (S. Ontario)	45	(40)
Mixed grain, spring triticale (N. Ontario)	70	(63)
Oat, spring rye (S. Ontario)	35	(32)
Oat, spring rye (N. Ontario)	55	(50)
Spring wheat	70	(63)
Winter barley, winter rye	90[3]	(81)
Winter triticale	80	(72)
Winter wheat	See Table 4–14.	

100 kg/ha = 90 lb/acre

[1] Where manure is applied or the preceding crop is a legume sod, reduce the nitrogen rates as shown in Table 9–7, *Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down*, on page 162, and Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page 164.

[2] See *Nitrate-Nitrogen Soil Test for Spring Barley*, this page.

[3] When not in rotation with tobacco.

General Recommendations

General nitrogen fertilizer recommendations for cereal crops are given in Table 4–13, *Nitrogen Requirements for Cereal Crops*, this page, Table 4–14, *Nitrogen Requirements for Pastry Wheat*, this page, and Table 4–15, *Nitrogen Recommendations for Spring Barley Based on Nitrate-Nitrogen Soil Tests*, opposite page.

Red Winter Wheats

The current recommended hard red winter wheat varieties in Ontario are not equivalent to Canadian Western Red Spring Wheat (CWRS) but are mid-strength or blend varieties with bread-baking and other unique qualities. High protein content may be required in these varieties to meet quality specifications. To achieve these protein levels, a higher rate of nitrogen fertilizer is often required. Limited field research would suggest that the optimum rate of nitrogen is 30–45 kg/ha (27–40 lb/acre) greater than for pastry (soft) wheat. Splitting nitrogen applications may increase protein, but often these increases are small enough that the split application is not economical.

Newer hard red varieties are constantly being evaluated. These varieties may not require increased nitrogen to achieve protein levels that maximize protein premiums.

Table 4–14. Nitrogen Requirements for Pastry Wheat

Nitrogen:Wheat Price Ratio	Expected Yield — t/ha (bu/acre) 4 (60)	5 (75)	6 (90)
	Most Profitable Nitrogen Application kg/ha		
5	75	95	110
6	70	85	105
7	65	80	100
8	60	75	95

100 kg/ha = 90 lb/acre

For soft red or soft white pastry wheat. The price ratio is the cost of the nitrogen in the fertilizer ($/kg N) divided by the selling price of the wheat ($/kg of wheat). See Appendix B, *Corn Nitrogen Rate Worksheet (Imperial) With Detailed Explanation*, on page 258. A maximum of 10 kg N/ha may be applied at seeding and the remainder top-dressed in early spring.

Price Ratio Example: If the price of UAN is $350/T, then the price per kilogram of N is $350 ÷ 280 = $1.25/kg. The value of wheat at $250/T is $0.25/kg. The price ratio is $1.25 ÷ $0.25 = 5. In other words, it takes 5 kg of wheat to pay for 1 kg of nitrogen.

Check with seed suppliers for advice on nitrogen rates for specific varieties.

Nitrogen for grain protein production is required later in the development of the plant than the nitrogen for yield. This makes hard wheat varieties ideally suited to use the nitrogen from slow-release nitrogen sources or organic sources (legume plowdown or livestock manure). Desired protein levels are often easier to achieve on livestock farms due to these factors.

Nitrate-Nitrogen Soil Test for Spring Barley

The nitrate-nitrogen soil test can be used to predict nitrogen requirements for spring barley in areas other than Eastern Ontario that receive less than 3,000 CHUs (see Figure 1–1, *Crop Heat Units (CHU-M1) Available for Corn Production*, on page 9).

Since soils can vary greatly in their ability to supply nitrogen, the general recommendations found in Table 4–13, *Nitrogen Requirements for Cereal Crops*, this page, may not be the most profitable for some fields. The amount of nitrate-nitrogen present in the soil near planting time can be a useful indicator of a soil's ability to supply nitrogen.

Consider a recommendation based on a spring nitrate-nitrogen test to be a useful guideline for formulating a nitrogen management program for spring barley (see Table 4–15, *Nitrogen Recommendations for Spring Barley Based on Nitrate-Nitrogen Soil Tests*, opposite page).

Table 4–15. Nitrogen Recommendations for Spring Barley Based on Nitrate-Nitrogen Soil Tests

Spring Soil Nitrate-Nitrogen 0–30 cm (kg/ha)[1]	Price Ratio[2]			
	8	7	6	5
10	138	147	156	165
20	107	114	122	129
30	76	81	87	93
40	44	49	53	57
50	13	16	18	21
60	0	0	0	0
100 kg/ha = 90 lb/acre				

For areas outside of Eastern Ontario that receive less than 3,000 CHUs.

[1] To convert to nitrate-nitrogen soil test (30-cm depth) from ppm to kg/ha, multiply by 4.

[2] The price ratio is the cost of the nitrogen in the fertilizer ($/kg N) divided by the selling price of the barley ($/kg of barley). See Appendix B, *Corn Nitrogen Rate Worksheet (Imperial) With Detailed Explanation*, on page 258.

Time and Depth of Sampling

Collect samples as close to planting time as practical (within 5 days of planting), allowing for sample shipping, analysis and receipt of results. Contact the accredited lab to determine sample turnaround times.

It is important that all cores in a field be taken to a 30-cm (12-in.) depth. To ensure that the sample is representative of the field, take the same number of cores and use a sampling pattern similar to that recommended for the standard soil test described in *Soil Sampling*, on page 156. Also see Appendix C, *Accredited Soil-Testing Laboratories in Ontario*, on page 260.

Where Caution Is Required

There are situations where the fertilizer recommendations based on nitrate-nitrogen soil tests should be adjusted. The nitrogen in manure or legumes applied or plowed down just before sampling will not have converted into nitrate and will not be detected by the soil test. Information will be provided with the soil test results on how to make appropriate adjustments.

Exercise caution if the recommendation is for large quantities of nitrogen and there is a history of barley lodging at lower rates of nitrogen. The nitrate-nitrogen soil test has not been adequately evaluated for:

- legumes or manure plowed down in the late summer or fall
- barley following legumes in a no-till system employing chemical burndown of the legumes

Table 4–16. Yield Loss Associated with Inaccurate Nitrogen Application Patterns

Yield t/ha (bu/acre)	
Low N	Full N
3.72 (55.3)	5.20 (77.3)

Source: P. Johnson, OMAFRA.

Based on two locations in Middlesex County, 1998, three replications at each location.

Uniformity of Nitrogen Fertilizer Application

To maximize yield, nitrogen must be applied uniformly across the field. Uniform application is more critical than the form of nitrogen fertilizer applied. Table 4–16, *Yield Loss Associated with Inaccurate Nitrogen Application Patterns*, this page, shows the yield loss associated with inaccurate spread patterns. A 1.48-t/ha (22-bu/acre) yield difference was found between the fully fertilized and under-fertilized strips in the field.

Urea-Ammonium Nitrate Solution (UAN) (28-0-0 or 32-0-0) applied with streamer nozzles gives excellent, uniform nitrogen application and has shown small yield advantages (2.5 bu/acre) as shown in Table 4–17, *UAN as a Herbicide Carrier*, next page. Urea or ammonium nitrate (calcium ammonium nitrate) can be applied using airflow technology, improving uniformity, although uniformity is not guaranteed. During humid days, urea can build up in the airflow tubes, restricting flow and affecting distribution. Be sure to maintain clear hoses to achieve a uniform spread pattern.

Spinner spreaders often have the greatest inconsistency in spread pattern. If spinners are employed, consider double spreading the field (i.e., 6-m or 20-ft centres at half the rate, instead of 12-m or 40-ft centres) to overcome this inconsistency.

UAN applied through streamer nozzles causes little or no leaf burn. Applying 28% nitrogen (UAN) as an overall broadcast treatment (using flood jet or tee-jet nozzles) to emerged cereal crops is **NOT RECOMMENDED**. Table 4–17, next page, shows the yield loss associated with this practice. The addition of 28% to a herbicide application, especially contact herbicides, will greatly increase leaf injury and yield loss (Plate 25 on page 283).

Timing of Nitrogen Application

Most nitrogen fertilizers for spring cereals are applied before planting and worked into the soil. This allows optimum crop utilization of the fertilizer, while minimizing the risk of losses through run-off or volatilization. It is acceptable to top-dress emerged

Table 4–17. UAN as a Herbicide Carrier

	Visual Injury (%)	Yield (bu/acre)
200 L/ha water	0	95
150 L/ha water + 50 L/ha UAN	3	95
100 L/ha water + 100 L/ha UAN	5	91
50 L/ha water + 150 L/ha UAN	7	91
200 L/ha UAN	9	89

Sikkema, University of Guelph (RCAT), 2008, in progress

spring cereals, particularly if a starter fertilizer has been applied at planting.

Winter cereals should only receive a small application of nitrogen fertilizer at planting because of the risk of nitrogen loss overwinter. The majority of the nitrogen should be applied in early spring, just as the crop is beginning to green up. There is no consistent advantage to splitting the nitrogen applications on spring cereals or winter pastry wheat.

Phosphate and Potash

Phosphate and potash recommendations for cereals are in Table 4–19, *Phosphate and Potash Recommendations for Cereals Based on OMAFRA-Accredited Soil Tests*, opposite page.

For information on the use of these tables, or if an OMAFRA-accredited soil test is unavailable, see *Fertilizer Recommendations*, on page 158.

Methods of Application

Where phosphate fertilizer is required for cereal crops, it is best drilled with the seed. Seed-placed fertilizers may include some or all of the required nitrogen and potash, depending on rates of application. For further information, see Table 9–21, *Maximum Safe Rates of Nutrients*, on page 176.

Plant Analysis

For cereals, sample the top two leaves at heading. Sample plants suspected of nutrient deficiency as soon as the problem appears. For plants less than 20 cm (8 in.) tall, sample the entire plant. For sampling at times other than heading, take samples from both deficient and healthy areas of the field for comparison purposes.

Take a soil sample from the same area and at the same time as a plant sample.

Table 4–18. Interpretation of Plant Analysis for Cereal Crops

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	2.0	2.7
Phosphorus (P)	%	0.1	0.5
Potassium (K)	%	1.0	3.0
Calcium (Ca)	%	–	1.0
Magnesium (Mg)	%	0.15	1.0
Boron (B)	ppm	3	40
Copper (Cu)	ppm	3	50
Manganese (Mn)	ppm	15	200
Zinc (Zn)	ppm	10	70

Values apply to the top two leaves sampled at heading.

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the critical concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

For more information, see Table 4–18, *Interpretation of Plant Analysis for Cereal Crops*, this page, and Appendix I, *Diagnostic Services*, on page 266.

Micronutrients

Manganese

Manganese deficiency frequently occurs when wheat, oat or barley are grown in an organic (muck) soil. It can occasionally occur in mineral soils high in organic matter and soil pH, and in very sandy soils. On oat, manganese deficiency appears as irregular, oval, grey spots on the leaves (Plate 26 on page 283). On barley and wheat, it appears more commonly as a light yellow colour on the leaves with the veins in the leaf remaining slightly darker green (see Plate 27 on page 283). Both soil tests and plant analyses are useful in predicting where manganese deficiencies are likely to occur. Both analyses are available at the OMAFRA-accredited soil testing laboratories.

Correct the deficiency as soon as it is detected by a foliar spray of 2 kg/ha manganese from manganese sulphate (8 kg/ha manganese sulphate) in 200 L of water. Use a "spreader-sticker" in the spray. If the deficiency is severe, a second spray may be beneficial. Winter cereals growing in areas of severe manganese deficiency may require an application in the fall to ensure winter survival.

Table 4–19. Phosphate and Potash Recommendations for Cereals Based on OMAFRA-Accredited Soil Tests

	Spring Barley, Spring Wheat, Mixed Grain		Oat, Spring Triticale, Spring Rye		Winter Wheat, Winter Rye, Winter Barley, Winter Triticale		Winter or Spring Grains Seeded Down	
Sodium Bicarbonate Phosphorus Soil Test (ppm)	**Rating[1]**	**Phosphate (P_2O_5)[2] Required kg/ha**	**Rating[1]**	**Phosphate (P_2O_5)[2] Required kg/ha**	**Rating[1]**	**Phosphate (P_2O_5)[2] Required kg/ha**	**Rating[1]**	**Phosphate (P_2O_5)[2] Required kg/ha**
0–3	HR	110	HR	70	HR	70	HR	130
4–5		100		60		60		110
6–7		90		50		50		90
8–9		70		30		30		70
10–12	MR	50	MR	20	MR	20	MR	50
13–15		20		20		20		30
16–20		20	LR	0		20		20
21–25	LR	0		0	LR	0		20
26–30		0		0		0	LR	0
31–40	RR	0	RR	0		0		0
41–50		0		0	RR	0	RR	0
51–60		0		0		0		0
61 +	NR[3]	0	NR[3]	0	NR[3]	0	NR[3]	0
Ammonium Acetate Potassium Soil Test (ppm)	**Rating[1]**	**Potash (K_2O)[2] Required kg/ha**	**Rating[1]**	**Potash (K_2O)[2] Required kg/ha**	**Rating[1]**	**Potash (K_2O)[2] Required kg/ha**	**Rating[1]**	**Potash (K_2O)[2] Required kg/ha**
0–15	HR	90	HR	70	HR	50	HR	90
16–30		80		50		40		80
31–45		70		40		30		70
46–60		50		30		20		50
61–80		40	MR	20	MR	20		40
81–100	MR	30		20		20	MR	30
101–120		20	LR	0	LR	20		20
121–150		20	RR	0	RR	0		20
151–180	LR	0		0		0	LR	0
181–210	RR	0		0		0	RR	0
211–250		0		0		0		0
251 +	NR[4]	0	NR[4]	0	NR[4]	0	NR[4]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR, and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] Where manure is applied, reduce the fertilizer application according to the amount and quantity of manure (see *Manure*, on page 164). For spring barley in an area with less than 2,800 CHUs, not manured and not following a legume sod, the nitrogen requirement is 70 kg/ha (see Table 4–13, *Nitrogen Requirements for Cereal Crops*, on page 98). If the soil test results are 11 for phosphate and 48 for potash, the phosphate requirement would be 50 kg/ha and the potash requirement 50 kg/ha. These nutrients could be supplied by drilling 250 kg (50 ÷ 20 x 100) of 5-20-20/ha to supply the phosphate and potash and broadcasting 170 kg of 34-0-0 or 130 kg of 45-0-0/ha to supply the recommended amount of nitrogen.

[3] A rating of NR may mean reduced yield or affected nutrient balance in crops.

[4] A rating of NR may mean reduced yield or quality of crops primarily due to magnesium deficiency. Natural levels above 250 occur occasionally on clay and clay loam soils but are not expected to cause problems because soils naturally high in potassium are usually high in magnesium.

Table 4–20. Effect of Different Fan-Speeds on Wheat Yield

	Fan Speed (rpm)							
	1,160	1,190	1,220	1,250	1,280	1,320	1,330	1,330
	Sieve Setting: 6 mm (¼ in.)							Front Closed
Good kernels on ground: per m² (per ft²)	172 (16)	125 (11.6)	340 (31.6)	263 (24.4)	379 (35.2)	446 (41.4)	470 (43.6)	461 (42.8)
Loss: t/ha (bu/acre)	0.06 (0.83)	0.04 (0.58)	0.11 (1.58)	0.08 (1.22)	0.12 (1.76)	0.14 (2.07)	0.15 (2.18)	0.14 (2.14)
Loss at 4.03 t (60 bu) yield: %	1.38	0.97	2.63	2.03	2.93	3.45	3.63	3.56

Source: Dr. Art Schaafsma, University of Guelph, Ridgetown College, 1996.

Case International 1644, Harus Wheat, Essex County, July 17, 1996. Travel speed 6.8 km/h (4.2 mph). Rotor speed 880 rpm.

Soil application is not recommended, regardless of source, because of the large amounts of manganese that would be required. In most cases, deficiencies in the plants are caused by a low availability of manganese from the soil rather than a lack of manganese. Adding more manganese to the soil will not often correct this.

Copper

Copper deficiency may occur in organic (muck) soils and is suspected on rare occasions in very sandy soils. The most common deficiency symptom is dieback from the tip of the leaf, often accompanied by twisting of the upper leaves. For information on correcting copper deficiencies, see *Micronutrient Fertilizers*, on page 161.

Boron

Boron deficiency has not been diagnosed in cereals. Boron applications can be toxic, causing a bleaching of leaf tissue in seedlings.

Zinc

Zinc deficiency in cereals does not appear to be a problem.

Do not apply mixtures of herbicides and foliar fertilizers to crop foliage unless recommended by competent authorities. Always consult the herbicide label.

Harvest and Storage

Optimizing Combine Adjustments

Operator manuals contain the best starting point for setting up a small grain harvest. Occasionally, conditions arise that require further adjustments. Harvest of fusarium-damaged grain, lodged crops or crops infected with dwarf or common bunt requires special attention. The easiest and best way to improve the grain sample in these situations is with proper combine adjustment. Often the difference between a marketable crop and sample grade wheat is in the combine set-up. Don't be afraid to experiment.

Storage of the crop allows the opportunity to upgrade the grain before delivery to an elevator or mill. This is particularly important for wheat infested with any of the bunt diseases. Many producers have experimented with re-cleaning the grain through screen cleaners, seed cleaners and fanning mills to upgrade the crop to a better sample. Elevator operators can also do this, for a fee. This can have tremendous economic benefit, where grain can be moved from salvage grade to milling grade. Upgrading the grain makes it much easier for the elevator to handle the crop and find a purchaser for the grain.

Fusarium-Damaged Grain

Combines use air blast to separate grain from the chaff in a normal harvest operation. Many of the *Fusarium*-infected kernels are small, shrunken and lighter than sound kernels. It is often possible to blow a large proportion of these *Fusarium*-damaged kernels out the back of the combine by increasing the air blast above normal ranges. In 1996, many producers operated combines at the maximum windblast to increase grade. Research conducted by Dr. Art Schaafsma (University of Guelph, Ridgetown College) in 1996 found a tenfold decrease in *Fusarium*-damaged kernels in the grain when fan speeds were operated at maximum blast (up to 300 rpm above book settings). Operating cleaning fans at these levels causes an additional loss of good kernels, up to 0.13 t/ha (2 bu/acre) (see Table 4–20, *Effect of Different Fan-Speeds on Wheat Yield*, this page). This small yield reduction is insignificant if the crop can be made marketable, rather than being downgraded to feed, sample or salvage.

Harvest should not begin above 16% moisture if significant *Fusarium* is present. High moistures reduce the ability to blow out lighter *Fusarium*-damaged kernels.

Slowing the forward ground speed of the combine may further reduce *Fusarium* levels. This allows increased separation of the grain mass, giving the increased windblast time to separate the good kernels from the infected kernels. Consider adjusting the cleaning sieves (chaffer) to a more wide-open setting. This directs the air blast vertically, slowing rearward movement of the grain mass and aiding cleaning and separation. Use caution to keep heads and straw particles out of the grain sample if the chaffer is opened.

Unfortunately, there will be times that the grain cannot be raised to milling standards. If this occurs, consider storing as much of the damaged grain as possible. Often, as harvest finishes, the pressure eases on those involved in handling the crop. Marketers and millers are able to assess the markets that do exist and the best way to condition wheat to fit that market.

Remember that wheat going into storage must be dry (14% moisture or below). Damp wheat allows the *Fusarium* to continue to grow and produce toxins, further downgrading the crop. Check stored grain frequently to ensure that the grain stays in condition.

Lodged Grain Crops

There are several effective options for harvesting lodged grain crops.

Grain Lifters

Setting up a combine for lodged wheat takes extra time and care while in the field. Although flexible cutter bars on floating soybean heads are standard on combines today, consider using grain lifters, which lift the crop above the cutter bar. This is an inexpensive way of maximizing yields.

Knife Adjustment

On floating cutter bars, leave the knife tilted down and run the header in the float position as if harvesting a soybean crop. Take care not to feed rocks into the combine if choosing this option.

Reel Adjustment

Adjust the reel on the combine. Most reels are permanently on the best setting for soybean harvest (newer combines have hydraulic adjustment from the cab), but this setting is not appropriate for a lodged cereal crop. Set the reel forward and adjust the tine angle to be more aggressive, allowing the reel to physically lift the crop up off the ground and above the knife. Check the operator's manual for suggested settings and fine tune from there.

Harvesting Direction

The last option, an unfortunate reality in some years, is to harvest the grain in one direction so the lodged grain is tilted towards the header rather than away.

Bunt-Infected Wheat

To avoid being forced into harvesting a bunt-infected crop, use resistant varieties of properly treated seed. However, when bunt does infect the crop, harvest and storage must focus on minimizing bunt balls in the sample and reducing the "fishy" odour following harvest.

Do not harvest bunt-infected crops at high moisture. Spores from broken bunt balls adhere more easily to damp grain. Harvest dry grain using slow cylinder speeds and open concave clearance to minimize the number of bunt balls broken during the harvest process. Operate cleaning fans at high speed to blow as many of the bunt balls and bunt spores out the back of the combine as possible.

Storage of bunt-infected wheat is an effective way to upgrade the grain. Aeration is the key. Store bunt-infected grain in storage facilities with lots of aeration capability. Aerate the grain until the odour has disappeared. Take care when removing the grain from storage, as the handling process can break remaining intact bunt balls and re-contaminate the grain. Belt conveyors are preferable to augers when moving bunt-infected grain. Use of aspiration during the handling process will often lift out remaining bunt balls and keep the grain in condition.

Never contaminate or attempt to blend bunt-infected wheat with clean wheat. It takes very little bunt to downgrade the grain. Blending will simply contaminate the good grain, not improve the damaged grain. For more information, see *Dwarf Bunt* and *Common Bunt*, on page 250.

Drying and Storing Wheat

Winter wheat is sometimes harvested at higher moisture contents because of impending wet weather or to reduce harvest losses. Wheat is considered dry at 14.5% moisture.

Winter wheat must be dried to 13%–14% moisture content for safe, long-term storage.

Drying Systems

Three different systems can be used to dry wheat:

- natural-air drying bin
- low-temperature dryers (less than 40°C)
- high-temperature or high-speed dryers (temperatures greater than 40°C)

Table 4–21. Recommended Airflow for Natural-Air and Low-Temperature Wheat Drying

Moisture Content (% wet basis)	Minimum Airflow	
	L/sec/m³	CFM[1]/bu
16	6.5	0.5
17	9.75	0.75
18	13	1.0

Adapted from Wilcke, William F., Hellevang, Kenneth J. *Wheat and Barley Drying*. FS-5949-GO, 1992. University of Minnesota, Extension Service.

[1] CFM = cubic feet per minute.

Natural-Air and Low-Temperature Drying

Natural air drying of wheat will only occur when the relative humidity of the outside air is below the equilibrium moisture content of the grain. The effectiveness of natural air drying systems is greatly reduced during rainy periods and at night when temperatures are cool and relative humidity levels are normally high. When air temperatures fall below 10°C, forced ambient air will not pick up as much moisture, and supplemental heat may be required. Extended periods of humid weather may also require additional heat to affect drying. Raising the temperature of the incoming air by 5°C will dry the air but should not overdry the grain at the bottom of the bin. See Table 4–21, *Recommended Airflow for Natural-Air and Low-Temperature Wheat Drying*, this page, for recommended airflow rates for natural-air and low-temperature wheat drying.

Minimum requirements for natural-air drying:

- full aeration floor in the bin
- level grain surface across the entire bin
- minimum airflow of 6.5 L/sec/m³ (0.5 CFM/bu), preferably 9.7 L/sec/m³ (0.75 CFM/bu) or more
- clean wheat with no weed seeds or fines
- accurate moisture determination of the wheat in the bin
- accurate outside air temperature and relative humidity measurement
- an understanding of wheat equilibrium moisture content
- on/off switch for the fan

A full aeration floor is essential to move air uniformly through the entire bin contents. With a partial aeration floor or air duct system, dead areas will exist, leading to potential spoilage problems. Weed seeds, green trash and fines accumulations in the bin will restrict or divert airflow. Air moving through the wheat mass will take the path of least resistance.

Table 4–22. Maximum Recommended Air Temperatures for Drying Milling and Seed Wheat

Dryer Type or Wheat End Use	Max. Temperature
Non-recirculating batch dryers	60°C
Recirculating batch dryers	60°C–70°C
Cross-flow continuous dryers	60°C
Parallel-flow dryers	70°C
Seed wheat	40°C

Copyright: *Farm Drying of Wheat*, Canadian Grain Commission, Sept 1992.

Wilcke, William F., Hellevang, Kenneth J. *Wheat and Barley Drying*. FS-5949-GO, 1992. University of Minnesota, Extension.

High-Temperature Drying

With high-temperature drying, large volumes of heated air, 40°C or higher, are used to accomplish drying in a few hours or days. Corn dryers could be used but it may be necessary to reduce the drying temperature to avoid loss of starch quality and germination. It is important not to exceed the recommended maximum air temperatures for drying milling wheat (see Table 4–22, *Maximum Recommended Air Temperatures for Drying Milling and Seed Wheat*, this page), which are dependent on the type of dryer used and the end use of the wheat.

For safe drying, the temperature of grain kernels should never exceed 60°C. Check the contract to determine if heated air drying is allowed to condition seed wheat.

The baking quality of wheat is reduced if the temperature of the grain reaches 60°C for any significant length of time. When heated air dryers are used, it is a worthwhile precaution to have samples evaluated to ensure the dried grain meets market standards.

Tough wheat can be dried with natural air under good drying conditions. Natural-air drying of wheat requires careful management by the operator since wheat gives up and takes on moisture easily. Only run the fan when outside conditions will result in drying progress.

Do not run the fan continuously, night and day, as the wheat will re-wet at night. The progress you make during the day will be undone during the night.

Determining Airflow

Sufficient airflow is needed to move drying air through the entire wheat mass. To remove moisture, the minimum airflow required is 6.5 L/sec/m³ (0.5 CFM/bu); anything less will only change the temperature but not the moisture content of the wheat. Higher airflow rates of 9.75 L/sec/m³ (0.75 CFM/bu)

Table 4–23. Equilibrium Moisture Content for Soft Winter Wheat Exposed to Air

	Relative Humidity				
Temperature	**50%**	**60%**	**70%**	**80%**	**90%**
0°C	12.5	13.5	14.6	16.1	18.2
5°C	12.1	13.1	14.2	15.7	17.9
10°C	11.7	12.7	13.9	15.3	17.5
15°C	11.4	12.4	13.5	15.0	17.2
20°C	11.1	12.1	13.2	14.7	17.0
25°C	10.8	11.8	13.0	14.4	16.7

or greater help speed up the drying process. These higher airflow rates may be difficult to achieve, requiring much higher fan horsepowers. The small kernel size of wheat causes the spaces between the kernels to be small. Moving large amounts of air through deep beds of wheat will take a large fan with high static pressure capability. If this bin and fan combination is capable of supplying 26 L/sec/m^3 (2 CFM/bu) when filled with corn, only fill it one-half to one-third that depth with wheat. With axial flow fans, filling the bin with wheat to one-third the depth of corn is a good starting point.

To determine the CFM/bu value for a bin, determine the number of bushels in the bin and the static pressure that the fan is operating against. A simple manometer connected to the air plenum below the perforated floor will show the static pressure (inches of water displaced in the column). See Figure 11–1, *Home-Built Manometer*, on page 183, for a diagram of a homemade manometer. Determine the fan output at the measured static pressure using the fan performance curve.

> To calculate CFM/bu airflow, divide the CFM output of the fan at the measured static pressure by the number of bushels in the bin (1 CFM/bu = 13 L/sec/m^3).

If adequate airflow cannot be achieved, one strategy is to partially fill the bin. In this way, the fan will be operating at less static pressure and will deliver higher airflow rates per bushel.

Equilibrium Moisture Content

Researchers have developed equilibrium moisture content tables (see Table 4–23, *Equilibrium Moisture Content for Soft Winter Wheat Exposed to Air*, this page) that allow the prediction of the final moisture content of winter wheat when exposed to air with a certain temperature and relative humidity.

For example, you can find the equilibrium moisture content of wheat exposed to outside air at 25°C and 80% relative humidity. In Table 4–23, for example, find the point at which the 25°C row and the 80% relative humidity column intersect. This point will be the equilibrium moisture content for wheat at the outside air conditions stated. Given enough time, the wheat will dry down to 14.4% moisture content.

When to Run the Fan

Air temperature and relative humidity levels should determine fan operation, not the time of day. On some days, drying can be accomplished from 9 AM until midnight, while on others it may only be from 9 AM to 6 PM. Check the temperature and relative humidity of the air frequently throughout the day. As the wheat loses moisture, drier outside air is needed to continue to make drying progress. If the equilibrium moisture content on a given day is less than the moisture content of the wettest wheat, drying is possible and the fan should be on. Install a humidistat that will activate the fan at preset humidity levels. The operator can adjust the relative humidity level at which the fan is activated.

The wheat at the top of the bin will be the last to dry. Each day of fan operation will push a drying front up through the bin. This drying front may not reach the top of the bin that same day. Be sure to take moisture samples at the same depth each time to know how the moisture content is changing at that depth. Bins with stirrators will have fairly uniform moisture levels throughout the entire bin as a result of the mixing that has been done.

Other Crop Problems

Insects and Diseases

Figure 4–6, *Cereal Crops Scouting Calendar*, next page, shows insects and diseases that could be causing the symptoms in the field. Individual descriptions of insects and diseases, scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, and Chapter 14, *Diseases of Field Crops*.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

Winterkill

Winter cereals can be destroyed during the winter and early spring period by frost heaving, ice, low temperatures and snow mould. Varieties differ in their ability to withstand these different winter stresses. This explains the regional adaptation of some varieties that may not perform well across the province.

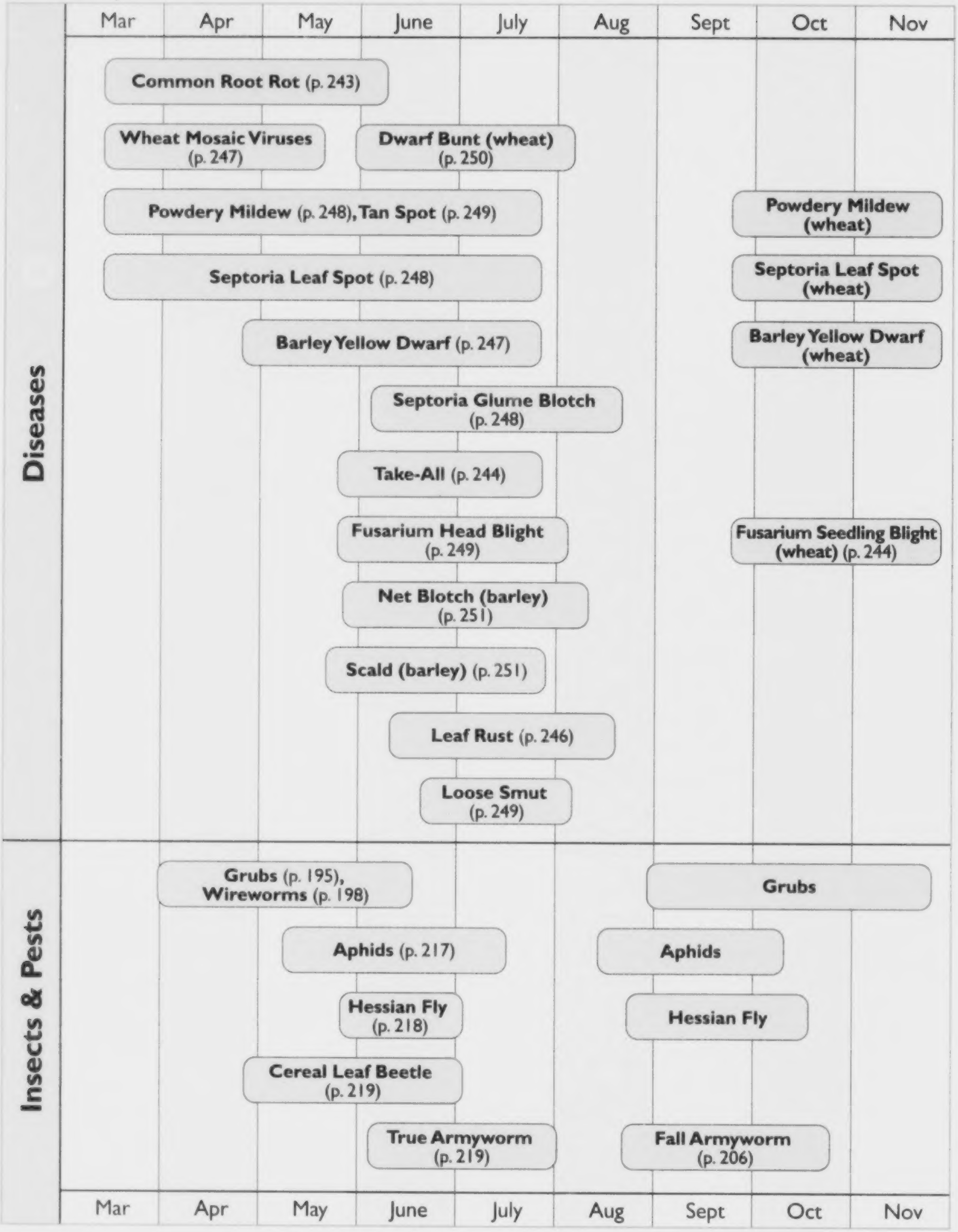


Figure 4–6. Cereal Crops Scouting Calendar

Select varieties to address the winterkill concerns of your area. Varieties grown in the Ottawa Valley need ice tolerance; those grown in the Lake Huron snow belt need snow-mould tolerance, while those grown in the heavy clays of Essex, Lambton and the Niagara peninsula need resistance to frost heaving.

Frost Heaving

The freeze/thaw cycles of early spring are one of the main reasons for winterkill in Ontario. As frost goes into the ground, it works under the crown and "lifts" the plant up (Plate 28 on page 283). If these freeze/thaw cycles are repeated enough times, the plant is ejected or "jacked" out of the soil. Roots are broken and left exposed above the soil, causing death of the plant due to desiccation. This process is referred to as frost heaving.

Deep-seeded wheat is not more resistant to frost-heaving injury. The primary root system does not anchor the plant in the soil. The secondary root system anchors the wheat plant in the soil, protecting against frost-heaving injury. The secondary root system of the wheat plant cannot develop deeper in the soil than the depth of the seed (see Figure 4–1, *Days to Emergence at Various Seeding Depths*, on page 90). When wheat is seeded deep, the plant develops the crown and secondary root system at about 2 cm (¾ in.) deep, as the crown develops in response to light. Regardless of planting depth, the secondary roots will not develop below 2 cm (¾ in.). To maximize resistance to frost heaving, wheat plants need an extensive secondary root system developed as deep as possible.

Ice

When a rapid snow melt or winter rain is followed by below-freezing temperatures, ice can form as a thick sheet across ponded areas. Even when the water is able to drain away below the ice sheet, the ice itself may prevent oxygen from getting to the plants and the wheat will suffocate and die below the ice.

Surface and subsurface drainage can help reduce the ponding, which leads to this problem. Should an ice sheet form (for example, during January and February), dormant wheat will only survive for approximately 2 weeks. Break the ice surface to allow gas exchange and to keep the wheat alive.

Cold Injury

Wheat will survive extremely cold temperatures before plant death occurs. Plants that have "hardened off" (gone dormant) can survive temperatures down to –24°C. Snow cover acts to insulate the crop from extremely cold temperatures, and even 7.5 cm (3 in.) of snow is sufficient to protect the crop from colder temperatures. Leaf tissue on plants that have not hardened off will withstand –9°C, making late spring frosts of little consequence. There was only 1 year in the last century when cold temperatures in Ontario destroyed the wheat crop.

While the wheat crop survives cold temperatures well, cold injury can reduce vigour and final yield.

Dry Edible Beans

5. Dry Edible Beans

Dry beans (*Phaseolus vulgaris*) belong to a class of legumes that are grown almost entirely for food. Production is mostly in Southern Ontario, and over 80% of production is exported. The main types grown in Ontario include navy (white), kidney, cranberry, black and otebo. Adzuki beans are only distantly related. Dry beans require special cultural management practices for optimum quality and profitability.

Tillage Options

Dry beans grow best in soils that are friable, loose and well aerated. The seedbed requirements are similar to those for soybeans, including a firm seedbed to enhance a uniform planting depth. The best stands come from beans that emerge within a week of planting. To accomplish this, it is important to have:

- uniform soil moisture
- good soil-to-seed contact
- secondary tillage limited to minimum required for seedbed preparation
- surface conditions that minimize risk for soil crusting

White and black beans can be successfully grown using either a conventional or no-till system. Conventional tillage is necessary for large-seeded bean types that are usually harvested by the pull and windrow method. In no-till systems, dry beans respond to some form of tillage in the seed zone at planting. This is largely due to their inherently small and poorly developed root system. Tillage coulters on the planting unit will provide the necessary seed zone tillage.

Beans are shorter when grown in a no-till system and therefore are more suited to narrow row production. Packing following planting is essential for dry edible beans where direct harvesting is planned and for dry edible beans planted no-till into corn stubble. Packing will prevent stones, cornstalks and contamination from dirt when combining.

Land planted to dry edible beans is susceptible to soil erosion. The crop canopy and crop residue only protect the soil for a relatively short period of time. For beans in wide rows, a crop canopy may only fully cover the soil during August.

Crop Rotation Considerations

A good crop rotation is the most important detail for high edible bean yields. Factors to consider when selecting a field for dry edible beans:

- soil type , structure, stoniness and drainage
- disease history
- weed control and herbicide carry-over

Soil Type and Structure

Dry edible beans are one of the most responsive crops to good soil structure. Heavy soils that have poor drainage, crust or are hard to till risk uneven emergence and poor stands. Soil remaining saturated for 24 hours will lead to severe damage to seedlings. Uneven emergence results in uneven ripening, delayed harvest and immature beans that increase the "pick" and result in lower grade and price when marketed.

Avoid growing dry edible beans in fields where compaction is a concern. Soil compaction is a serious dry bean production issue that restricts root growth, promotes root disease and increases risk of herbicide injury. Yield reductions from compaction and poor soil stucture can be as high as 30%–50%. Compaction takes time to overcome and cannot be alleviated with tillage alone.

Disease

A rotation where beans are grown only once in 3 years (or longer) is essential to avoid the build-up of diseases. The most common diseases encouraged by short rotations are root rots and white mould (*Sclerotinia*). Soybeans, canola or sunflowers are not the best rotation crops since they are all susceptible to white mould. Root rots are challenging to control through rotation because they have a wide crop-host range. The organisms that cause root rots are often invasive, infecting plants that are under stress. Soil compaction, poor drainage, frequent cropping to beans and other factors cause plant stress that favours root rot. Dry beans are also hosts for soybean cyst nematode (SCN). The impact of SCN on various dry bean market classes is under investigation. For additional information about SCN and other dry edible bean diseases, see Chapter 14, *Diseases of Field Crops*.

Weed Control

Options for controlling annual broadleaf and perennial weeds are limited in dry edible beans, so weeds must be controlled in the previous crop. Weeds present at harvest may also create quality problems (seed staining). Perennial weeds, such as pokeweed and nightshade, cause severe staining of beans at harvest. Corn is often favoured as a previous crop because of the number of options for controlling probem weeds.

Dry edible beans are very sensitive to certain herbicides. To reduce carry-over injury from previous crops, select herbicides carefully the year prior to bean production.

When all the factors have been taken into consideration, most often the ultimate rotation crop for dry edible beans is corn; forages or cereals also make a good rotation crop. A previous crop of corn provides a good opportunity to control weeds and an effective break in edible bean diseases. A cereal crop in which weed control was good would be preferred over a corn field where compaction following a wet harvest might be an issue. Forages provide the best soil structure, but soil insects and weed pressure can be an issue. For more information on appropriate crop rotations for dry edible beans and precautions under different tillage systems, see Chapter 8, *Soil Management*.

Variety Selection

Before deciding on a marketing class, carefully consider:

- various marketing opportunities
- contract requirements
- unique production requirements and risks
- quality standards

Select varieties based on yield, maturity, standability and disease resistance/tolerance. White beans are rated for their suitability for direct harvest. Varieties are also rated for resistance to two important diseases: bean common mosaic virus (BCMV) and anthracnose. When dry edible beans are grown in narrow rows, select varieties with an upright plant type, since direct harvest is the only option.

Maturity — CHUs

Choosing varieties of an appropriate maturity is of primary importance (see Figure 1–1, *Crop Heat Units (CHU-M1) Available for Corn Production*, on page 9, for the heat unit rating for your area). Select varieties that will mature within the first half of September, when the weather is generally more favourable for harvest and the opportunity for timely planting of winter wheat exists. Harvesting in dry weather will help maintain high-quality beans.

For a list of varieties and their heat unit ratings, see distributor information and the OMAFRA Infosheet, *Performance Trials for Dry Edible Beans*, at the OMAFRA website at www.ontario.ca/crops.

Table 5–1. Planting Date Guidelines

Geographic Area	Planting Date Guidelines
Less than 2,900 CHUs	May 26–June 6
2,900–3,100 CHUs	May 30–June 10
Greater than 3,100 CHUs	June 7–June 20

Maturity of beans is rated for two areas: full/mid-season and short-season areas. The differences between these general areas have more influence on a variety's "days to maturity" than does the planting date.

Planting and Crop Development

Seed Quality

Using high-quality, pedigreed seed from inspected fields is important for early season vigour and reducing the risk of seed-borne disease. Common bacterial blight, anthracnose and bean common mosaic virus can be serious seed-borne diseases some years. Ensure that seed is free from mechanical injury and weather damage. Almost all coloured bean seed (except black bean seed) is imported from arid growing regions in the U.S. where there is a low incidence of bacterial blight and anthracnose. White and black bean seed may originate from pedigreed seed production in Ontario or the U.S. All seed should be tested for germination. See Appendix F, *Ontario Laboratories Offering Custom Seed Germination Testing*, on page 263. Poor-quality seed, including mechanically damaged seed, can result in reduced germination and vigour, uneven emergence, stunting or even "bald-headed" plants (plants without true leaves). Handle seed gently by:

- minimizing the distance seed falls
- using brush augers and conveyors
- being aware of seed moisture, since seed with low moisture (<16%) is more prone to mechanical damage and slightly slower emergence

Planting Date

Table 5–1, *Planting Date Guidelines*, this page, displays the guidelines for planting dates according to geographic regions.

The highest yields are obtained by planting within these planting dates. The planting date of coloured beans is dependent upon both variety and the number of crop heat units. Check with the seed distributor for variety-specific planting recommendations.

Table 5–2. Seeding Rates for White Beans

Number of Seeds		Row Width cm (in.)		
		36 (14.5)	53 (21)	76 (30)
		Number of Seeds/m of Row[1] (seeds/ft)		
		10–13 (3–4)[2]	11.5–15 (3.5–4.5)[3]	15–16 (4.5–5.0)[4]
/kg	/lb	Seeding Rate (kg/ha)		
4,500-5,000	2,000-2,300	72-83	54-62	42-48
5,000-5,500	2,300-2,500	66-72	50-54	38-42
5,500-6,000	2,500-2,700	61-66	46-50	36-38
6,000-6,500	2,700-3,000	55-61	42-46	32-36
100 kg/ha = 90 lb/acre				

[1] Adjust seeding rates for germination percent and expected percent emergence.

[2] Seeding rate of 369,000 viable seeds/ha (150,000 seeds/acre).

[3] Seeding rate of 272,000 viable seeds/ha (110,000 seeds/acre).

[4] Seeding rate of 222,000 viable seeds/ha (90,000 seeds/acre).

Dry edible beans are less vigorous than soybeans and for this reason need to be planted when soil conditions are warm and moist, ensuring quick, uniform emergence. The ideal soil temperature for germination is above 15.5°C. At temperatures below 13°C, emergence will be slower, increasing the risk of damage from herbicide injury, soil crusting and root rot. Planting within the appropriate dates will allow the crop to avoid hot, dry weather during flowering and ensure a timely harvest. Dry edible beans are less able to adapt to a shorter growing season from late planting than soybeans. Under late planting conditions, carefully consider when dry edible beans will mature before continuing to plant.

Seeding Rates

Edible bean seed size varies greatly. Check to ensure that the planter is calibrated properly to plant the correct number of seeds per metre of row. Table 5–2, *Seeding Rates for White Beans*, this page, displays the seeding rates for white beans according to row width. Seeding rates should be adjusted for seed quality and germination, field conditions and field history.

Seeding rates for coloured beans are shown in Table 5–3, *Coloured Bean Seeding Rate*, this page. For large-seeded coloured beans, the recommended seeding rate is 11.5–16.4 seeds/m (3.5–5 seeds/ft) in 53–76 cm (21–30 in.) rows. For specifics on seeding rates, consult with the seed supplier.

Table 5–3. Coloured Bean Seeding Rate

Row Width	Seeds/m of row[1] (/ft of row)	Final Plant Stand/ha (/acre)
53 cm (21 in.)	9.5–11.5 (2.9–3.5)	173,000–205,000 (70,000–83,000)
75 cm (30 in.)	11.5–15.1 (3.5–4.6)	148,000–198,000 (60,000–80,000)

[1] Suggested seeding rates vary significantly between market classes. Check with seed distributor for recommended rates. Seed sizes can vary between lots; check the seed tag for seeds/kg (seeds/lb).

In conditions where reduced emergence is a risk, increase seeding rates by up to 10%. High-risk conditions could include seeding into heavy soil, late or very early planting, deeper plantings or expected seedling loss from wireworm or seed corn maggot injury.

Seeding rate can be calculated using seeds/lb found on seed tag with the following formula:

Seeding rate (kg/ha or lb/acre)
= desired final plant population ÷ seedling survival rate ÷ seeds per kg or per lb

Example: Cranberry beans
60,000 plants/acre desired population
85% seedling survival
800 seeds/lb

Seeding rate
= 60,000 ÷ 0.85 ÷ 800
= 88 lb/acre

Seeding Depth

The seeding depth for dry edible beans is critical for uniform emergence. Frequently, poor stands are the result of not planting into moisture. Planting depth should be at least 1.2 cm (½ in.) into soil moisture. Uneven emergence results in uneven maturity. A seeding depth of 4–6 cm (1½–2½ in.) is normal, but deeper plantings of up to 9 cm (3½ in.) may be necessary to seed into moisture. Beans planted deeper are more susceptible to crusting problems. Some older drills cannot provide accurate depth control. In these situations, a planter may be a better option. Seed drills should have gentle seed distribution devices, depth bands or depth gauge wheels and press wheels to ensure uniform seed placement and coverage. Rolling or packing a field prior to planting helps firm the seedbed and conserve moisture, and can help control planting depth when seeding with a drill. Packing after planting helps level out ridges, pushes down small stones and conserves moisture, however, it also makes the soil more susceptible to crusting.

Row Width

Row widths of 70–75 cm (28–30 in.) are standard for both white beans and coloured beans when the bean crop is to be pulled and windrowed. Narrow row widths of 36–56 cm (14–22 in.) are most suitable if the white bean crop is to be direct harvested. Row width trials with no-till white beans produced yields 14% higher in narrow row widths (i.e., less than 56 cm or 22 in.) compared to wide rows. In narrow rows, it is important to select white bean varieties with an upright plant type and good tolerance to white mould. The percentage of emergence may be greater in wide rows seeded with a corn planter than solid-seeded with a grain drill due to:

- more uniform and accurate seed depth placement
- better seed coverage
- more seeds per linear metre (foot) of row to push up through a surface crust, i.e., 16 seeds/m (5 seeds/ft) of row in 76-cm (30-in.) rows versus 10–13 seeds/m (3–4 seeds/ft) in 36-cm (14-in.) rows
- seeds not being planted in tractor-tire tracks

In narrow rows, emergence can be a problem for beans planted into tractor tracks. Some growers adapt equipment to harrow or cultivate between the tractor tires and the planter. The advent of rod pullers has enabled beans planted in 50–56-cm (20–22-in.) rows to be pulled and windrowed.

Inoculation

Inoculation trials with dry edible beans have shown no advantage to the use of inoculant.

Dealing With Soil Crusting

Heavy soil types may crust severely, particularly if hot, dry conditions bake the soil surface and inhibit bean emergence. Soil loosening and aeration may be required. There is no advantage to waiting once the crust has been identified. Waiting may increase the lack of uniformity of the stand. There is a point in time where it is better to have a lower, more uniform stand, than a stand with a higher population, but uneven. All of the following have been used successfully (and unsuccessfully) in breaking crusted soils:

- rotary hoe
- culti-packer
- coulter-carts
- no-till drill
- planter
- harrows

Typically the rotary hoe can reduce bean stands by 5%–10%, but the extra beans that emerge more than compensate for this reduction. Rotary hoeing during the "hook" stage of bean emergence will result in significant plant losses. Rotary hoeing during mid-day, when bean plants are more flaccid, or limp, will reduce plant damage. Adjust the equipment over a short distance and check that the percentage of bean plants buried or uprooted is less than 10%. It is normal for the crop to look a little "tough" following rotary hoeing. Target speed is 10–20 km/hr. Weed control will also be enhanced when uprooted weeds dry out in mid-day heat. Aim to start and stop abruptly at the end of the field to effectively control weeds.

Replant Decisions

The decision to replant can be one of the most difficult decisions for a producer to make. Stresses on the crop are additive and have a greater impact on dry edible beans than soybeans. For an adequate stand of dry edible beans, there should be a minimum of two-thirds-to-three-quarters of a full stand. Dry edible beans have a limited ability to branch and compensate.

Minimum number of healthy plants per foot or row should be 2–2.5 in 38–56-cm (15–22-in.) rows; 3–4 plants/ft in 76 cm (30 in.) rows and 1.5–2 plants/ft in 18 cm (7 in.) rows. (Based on good growing conditions, the good health of the remaining plants, a uniform stand and un-compacted soil.)

Before replanting, consider the cause of the poor stand, the date of replanting, the remaining population of healthy plants, plant uniformity and weed control needs. Cranberry beans generally perform better than white beans or other coloured beans under late-planting scenarios.

Plant Development

Dry beans vary considerably in their plant architecture from upright to prostrate. Most of the commonly grown bean-types have a semi-determinate growth habit, meaning they continue to grow once flowering begins and develop short to long vines, but not to the same extent as the indeterminate types. Determinate types tend to flower and ripen over a shorter period which makes them more susceptible to moisture and heat stress than indeterminate types, which flower over a longer period.

Table 5–4. Vegetative and Reproductive Growth Stages of Dry Beans

Stage Abbreviated	Stage Title	Description
VE	hypocotyl emergence	• Seedlings emerge from the soil (crook stage)
VC	cotyledon & (unrolled unifoliate)	• Hypocotyl straightens, cotyledons (seed leaves) unfold, and unifoliates visible.
V1	first trifoliate	• First fully developed trifoliate leaf
V2	second trifoliate	• Second trifoliate
V3	third trifoliate	• Third trifoliate unfolds
V4	fourth trifoliate	• Fourth trifoliate • Branches begin to develop in leaf axils
Vn	trifoliate n	• Nth trifoliate develops at node N-2 • New node every 3–5 days
R1	first flower	• One open flower per plant Determinate (Type 1) plants may begin to flower by 5th trifoliate stage (V5) • Indeterminate (vine) types begin to flower by 8th trifoliate stage (V8)
	30% flower	• Open and dying blossoms are present, but no evidence of pods • 30% of total blossoms that will appear are open
R2	50% flower	• Appearance of first pods (pin beans)
R3	early pod set	• One pod has reached maximum length
R4	mid pod	• 50% of pods have reached maximum length
R5	early seed fill	• One pod per plant with fully developed seeds
R6	mid seed fill	• 50% of pods with fully developed seeds
R8	physiological maturity	• 80% of pods have changed colour from green to mature colour

Determinate Type (Bush)

Determinate market types, such as cranberry beans and some early varieties, are more compact in growth. For varieties that are determinate in growth, the stem stops upward growth when terminal flowers develop on main stem or side branches. Market classes that are determinate (Type 1) include most cranberry, light and dark red kidney beans.

Indeterminate Type (Vine)

Most other bean types are indeterminate, where they continue to develop new growth on vines, even when flowering begins.

In addition to determinate and indeterminate plant types, the growth of beans is also identified as:

Type I — determinate bush growth habit, for example, most cranberry beans, very early white bean varieties.

Type II — upright short vine, narrow plant with 3–5 branches for example, most white, black, kidney, otebo varieties.

Type III — plants with weak main stem that produces a vine that is prostrate along the soil surface.

The vegetative and reproductive stages of dry bean growth are indicated in Table 5–4, *Vegetative and Reproductive Growth Stages of Dry Beans*, this page. Vegetative stages are described by the number of trifoliates on the main stem. Trifoliates are counted when the edges of unfolding leaves no longer touch. Dry beans are normally self pollinated.

Fertility Management

Nitrogen

Nitrogen fertilizers are not usually necessary for dry edible beans. However, where phosphate fertilizers are banded, a small amount of nitrogen (10 kg/ha or 9 lb/acre) may improve the availability of the phosphate. Where edible bean yields have been low due to bronzing or root rots, apply up to 100 kg/ha (90 lb/acre) of nitrogen before planting. Under these conditions, nitrogen will increase yield but will not cure the bronzing or the root rot. Seed size was found to increase slightly by the application of nitrogen. Nitrogen application potentially can delay maturity, particularly following high legume sod or where manure is applied.

Table 5–5. Phosphate and Potash Recommendations for Dry Edible Beans Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating[1]	Phosphate (P_2O_5) Required kg/ha	Ammonium Acetate Potassium Soil Test (ppm)	Rating[1]	Potash (K_2O) Required kg/ha
0–3	HR	80	0–15	HR	120
4–5		60	16–30		110
6–7		50	31–45		90
8–9		40	46–60		80
10–12	MR	30	61–80	MR	60
13–15		20	81–100		40
16–25	LR	0	101–120		30
26–60	RR	0	121–150	LR	0
61 +	NR[2]	0	151–250	RR	0
			251 +	NR[2]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] There is no expected agronomic response from the additional application of nutrients, and there is the potential for additional application of the nutrient (commercial fertilizer and/or manure) to reduce crop yield and/or quality. For example, additional phosphorus application to a soil testing more than 60 ppm of phosphorus could induce a zinc deficiency on soils low in zinc and may also increase the risk of phosphorus movement to surfacewater, while additional potash application to a field already testing more than 250 ppm of potassium could induce magnesium deficiency on soils low in magnesium.

Phosphate and Potash

Phosphate and potash recommendations for dry edible beans are presented in Table 5–5, *Phosphate and Potash Recommendations for Dry Edible Beans Based on OMAFRA-Accredited Soil Tests*, this page. For information on the use of this table or if an OMAFRA-accredited soil test is unavailable, see *Fertilizer Recommendations*, on page 158.

Methods of Application

To avoid seed burn, do not place fertilizer in contact with the seed. The fertilizer may be broadcast and plowed down, worked in before planting or applied through a planter that has a separate attachment for fertilizer placement.

Plant Analysis

For dry edible beans, sampling the top fully developed leaf (three leaflets plus stem) at first flowering is recommended. See Table 5–6, *Interpretation of Plant Analysis for Dry Edible Beans*, opposite page. Sample plants suspected of nutrient deficiency as soon as the problem appears. If sampling at other than the recommended time, collect samples from both healthy and injured areas so comparisons can be made correctly. Take a soil sample from the same area and at the same time as a plant sample. Values in Table 5–6 apply to the top fully developed leaf (three leaflets plus stem) at first flowering.

Micronutrients

Manganese

Manganese deficiency in dry edible beans has been diagnosed occasionally in Ontario. This problem is more likely to occur on muck soils or on very sandy soils. Plants with manganese deficiency have pale green-to-white upper leaves. The veins of affected leaves will remain green. Correct the deficiency as soon as it is detected by spraying the foliage with 2 kg/ha of actual manganese (1.8 lb/acre) from manganese sulphate (8 kg/ha or 7.1 lb/acre of manganese sulphate) in 200 L (53 gal) of water. Use of a "spreader-sticker" is recommended.

In good growing conditions, the affected leaves should green up in 4–5 days. Chelated manganese products are equally effective if applying the same amount of manganese, but they are about 10 times the price of manganese sulphate. Low rates of chelated manganese are not effective and may make the manganese deficiency worse.

In general, beans will give a profitable response to manganese in the parts of the field where manganese deficiency is showing. There is no benefit to applying manganese to beans without deficiency symptoms.

Table 5–6. Interpretation of Plant Analysis for Dry Edible Beans

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	4.00	5.5
Phosphorus (P)	%	0.15	0.5
Potassium (K)	%	1.20	2.5
Calcium (Ca)	%		5.0
Magnesium (Mg)	%	0.10	1.0
Boron (B)	ppm	10.0	55.0
Copper (Cu)	ppm	4.0	30.0
Manganese (Mn)	ppm	14.0	100.0
Zinc (Zn)	ppm	14.0	50.0

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

Zinc

Zinc deficiency rarely occurs in beans. It is most likely to occur in spots where the topsoil has been lost. Zinc deficiency can be corrected by foliar spray application of 0.5% zinc sulphate spray in 190 L/ha (76 L/acre), plus wetting agent. One kilogram (2.21 lb) of zinc sulphate in 200 L (53 gal) of water makes a 0.5% solution. Zinc chelate is also effective as a spray. Soil application is not effective.

Boron

Beans are very sensitive to boron and should not be grown in a field where boron was applied to rutabagas the year before.

Harvest and Storage

Producing beans that are clean, bright and whole is the ultimate goal. Dry edible beans are sold to consumers on eye appeal. This is why quality and colour are so important. It is important to recognize the two important factors in the grading of beans — dockage and pick.

Dockage is anything foreign that is removed through the screening process. Some items can only be partly removed through screening, such as corn, soybeans, weeds or other crop types. Items that can cause a load to be refused include metal, glass, etc., and severe staining. Corn in a sample can also result in the rejection of a load, because it may be assumed the corn is GMO.

Pick refers to the percentage (weight basis) of defective beans including splits, checked seed coats, discoloured beans, mishappen, contrasting types and foreign material that remains after dockage. The dollar charge for pick is double; equal to the weight loss from picked beans plus the cost to remove this type of damage.

Dry edible beans can be a sensitive crop to harvest. Weather conditions in the fall can cause some bean types to deteriorate in quality much quicker than others. Kidney, dutch brown and black beans tend to withstand more adverse weather at maturity than the white navy, cranberry and white kidney types. Larger seeded coloured beans tend to absorb more moisture after a rain, requiring more time to dry down. It is therefore important to know the quality standards for the crop's market class.

The recommended range of moisture for harvest is 16%–20%. Harvesting outside this range will greatly reduce quality. Low moisture contents will increase the levels of split seeds and cracked seed coats. Wet or immature beans will become stained from the leaves, stems and dirt.

There are two common methods of harvesting dry edible beans: pulling followed by windrowing, and direct-combining.

Pulling, Windrowing, Combining

Beans planted in wide rows are usually harvested after pulling, which cuts the plants 3–5 cm (1¼ in.) below the soil surface and pulls plants from two or more rows into a single row with a windrower. Beans are pulled when 90% of pods have matured and turned buckskin brown. To prevent pod drop and shattering losses, pull beans early in the morning when the plants are tough and damp with dew. Beans are harvested later the same day with an edible bean or conventional combine equipped with a windrow pick-up attachment. Since prolonged exposure of the mature crop to excessive moisture will result in reduced quality, it is important to harvest the crop as soon after pulling as possible. Larger-seeded bean types require specialized combining in order to meet quality standards set by the market. Under good conditions, seed losses of 3%–5% are normal during harvest (i.e., 1% loss pulling and windrowing, 1% at combine pick-up, and 1%–2% cleaning and threshing).

Direct Combining

Bean types most suited to direct harvest include white beans with upright plant type, adzuki beans, black beans and pinto beans. Larger-seeded bean types require specialized combines in order to meet the quality standards of the market.

Table 5–7. Average White Bean Harvest Loss

Harvest Method[1]	Precleaning Loss: %		Cleaning Loss: %		Total Loss: %	
	Average	Range	Average	Range	Average	Range
Pull and windrow rod cutter	1.6	1.1–5.0	2.1	0.8–3.6	3.7	2.9–5.3
Pull and windrow knife cutter	2.3	1.1–10.9	2.4	1.4–5.7	4.7	2.6–12.3
Direct harvest finger/air reel	6.9	2.9–10.4	1.2	0.6–1.9	8.1	3.5–11.4
Direct harvest finger reel	11.7	3.3–20	2.0	1.0–2.0	13.7	5.4–21.9

Source: Harvesting Michigan Navy Beans, Michigan State University.

[1] Includes only those trials where equipment was operating as intended.

Combine enhancements help reduce harvest losses and minimize dirt, splits and damage to the beans. The cleaning and threshing characteristics of the crop will change throughout the day as moisture content changes. Combine set-up should include:

- Knives kept sharp to minimize shatter losses.
- Cylinders run only fast enough to thresh the crop. Run as much material as possible through the cylinder to minimize seed damage. Cylinder speeds on many combines do not go below 250 rpm, which can be too fast for easily threshed beans. Cylinder slow-down kits, which include a smaller diameter drive pulley and a belt, are available.
- Unloading augers run slow and full to minimize seed damage. The short vertical auger on the combine (turret auger) that takes seed from the bottom of the tank to the main unloading auger is a point of high seed damage. Some bean growers have changed unloading augers to conveyer belt systems.
- Combine ground speed set about two-thirds the speed used for harvesting soybeans.
- Vine lifters raising low hanging pods before the plant is cut. This can be one of the greatest benefits when harvesting varieties without a strong upright plant type.
- Flexible floating cutter bar adjusted to clip the bean plants as close to the ground as possible. This will help minimize the cutting of low-hanging pods and associated seed loss. The knife must cut cleanly and quickly to avoid shaking the plants, splitting pods and shattering beans. Most losses that occur are shatter loss. Ontario studies have shown that a flexible floating cutter bar can reduce losses by 25% compared to a conventional floating header. In addition a "quick-cut" sicklebar reduced loss by up to 40% compared to a standard sicklebar. Table 5–7, *Average White Bean Harvest Loss*, this page, displays the results from harvest loss comparisons made between four harvest methods on several farms in Michigan in 1990 and 1991.
- An air reel used to significantly improve intake of plants into the combine and reduce losses at the knife. The air blast keeps weeds and bean plants off the knife, offering better cutter bar visibility without shoving stones into the header. The biggest benefit of the air reel is demonstrated under difficult harvest conditions, when the crop is lodged or the volume of crop is reduced. Under good conditions, harvest losses may be as low as 3%, regardless of whether an air reel is used. Late in the day, as pods dry, header losses can reach more than 20% with a standard pick-up reel, while losses with an air reel are only 10%.
- A modified harvest pattern to improve yield and quality. Travelling against the direction of lodging allows the harvest of leaning branches and low-hanging pods and can reduce stubble losses. In an unevenly maturing or weedy crop, delay harvest in the affected areas until they are mature or they can be treated with a desiccant.

Quality Preservation at Harvest

Occasionally, the crop may be ready to harvest but the field or part of the field may still be green or weedy. Harvesting when green stems or green weeds are present may result in stained beans. Products are available for harvest aid to burn down weeds and desiccate the crop. See OMAFRA Publication 75, *Guide to Weed Control*, for more information. Similarly, weeds such as Eastern black nightshade and American pokeweed can cause severe staining. Where direct harvest is intended, a desiccant should be applied to dry the remaining green tissue.

Secondary growth can occur as plants begin to mature, particularly when rainfall follows an extended dry period. Special effort should be taken to maintain seed quality. Before harvesting, the combine should be cleaned of any residual seed of previously harvested crops. If on-farm storage is necessary, store individual varieties of beans in separate bins that are free from other grains and oilseeds. Harvested beans should be kept free of stones, glass and other seed-size contaminants. Failure to maintain the purity of the crop can result in lost value.

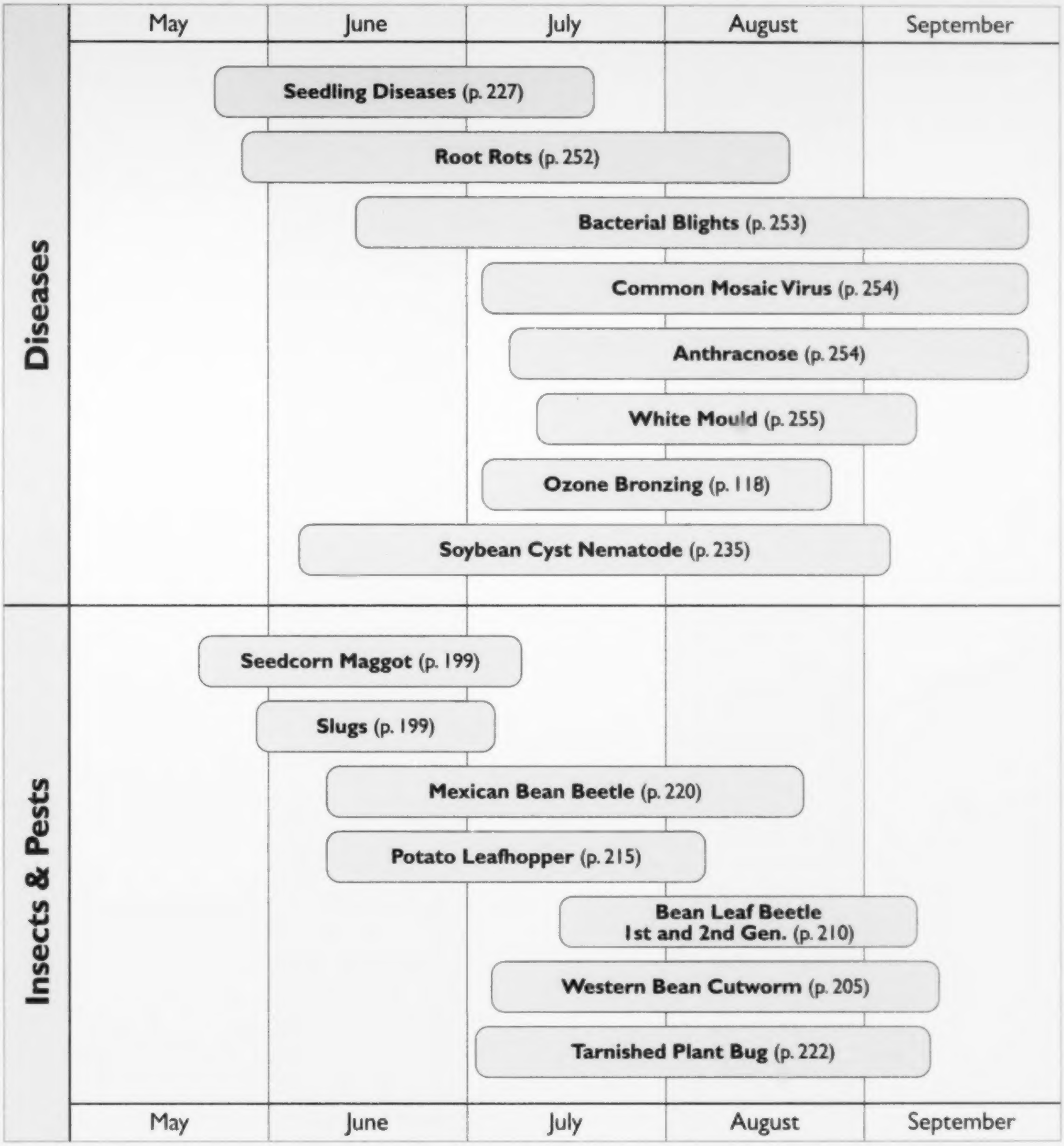


Figure 5–1. Dry Edible Bean Scouting Calendar

Other Crop Problems

Insects and Diseases

Figure 5–1, *Dry Edible Bean Scouting Calendar*, this page, shows insects, pests and diseases that could be causing symptoms in the field. Individual descriptions of insects, pests and diseases, scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, and Chapter 14, *Diseases of Field Crops*.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

Frost and Hail Damage

Both frost and hail can be devastating to a bean crop. The extent of early-season frost damage will depend upon where the plants were damaged. If the plant is damaged below the cotyledons, it will not recover. If the growing point is damaged, but the lower stem remains intact, the plant will send out new shoots from the base of the leaves or cotyledons. Wait a few days before replanting to see if these shoots appear.

When evaluating hail damage, check for bruising on the plant stem. Damage to the stem will make it more difficult for the plant to recover. It can also lead to increased stem disease. When the pods are damaged by hail, the seeds or entire pods will often rot. Dry edible beans have much more limited ability to recover from hail than soybeans.

If frost occurs close to maturity, pods that are yellow-to-brown are often sufficiently mature to escape damage. Green beans will shrivel, retain their off-green colour and increase "pick." Delaying harvest until the beans dry down sufficiently will help prevent staining and improve separation.

Bronzing

Bronzing is not caused by a living organism or pathogen but instead is the result of ozone damage to the leaf surface. A reddish-brown flecking or "bronzing" occurs on the upper leaf surface (Plate 29 on page 283). Affected leaves are often the highest leaves on the plant. Bronzing often occurs shortly following an ozone event. The number of leaves affected varies, depending on exposure duration. Symptoms may be more severe on plants under moist conditions. Under dry conditions, plants are more tolerant to ozone. The amount of damage found on the plant or in an area often corresponds to air pollution alerts or heavy thunderstorms. These conditions can result in atmospheric ozone being forced down onto the crop. Ozone is also produced when lightning strikes. The higher the concentration of ozone and the longer the duration, the greater the impact on the crop. Use tolerant varieties in areas that have a history of ozone events.

Seed Quality Problems

Poor seed quality reduces germination and vigour of seedlings. Mechanically damaged seed may cause bald-headed beans (beans that emerge, but have no growing point). This injury should not be confused with symptoms of seed corn maggots, which will leave the seedlings ragged in appearance. Poor-quality seed can also cause seedlings to have broken or cracked cotyledons, or hypocotyl. Damaged seedlings are more prone to diseases and insect damage. Plant only high-quality certified seed. Treat seed with a fungicide at planting to protect against seedling disease. Handle seed gently to minimize mechanical damage.

6. Spring and Winter Canola

Spring canola is an oilseed crop well suited to the cool, temperate areas of Ontario. Seeding and management of winter canola are similar to that of spring canola. The differences in required management are outlined below.

Tillage Options

Conventional Tillage

Most canola is grown using conventional tillage. Lumpy seedbeds interfere with seed-to-soil contact. Fall primary tillage is preferred on clay or clay loam soils so that spring tillage establishes a suitable seedbed. However, keep spring secondary tillage to a minimum to preserve soil moisture and minimize the risk of crusting.

Mulch Tillage and No-Till

Seeding canola with no-till and reduced tillage systems can be successful provided the seeding equipment can place the seed below the residue and in firm contact with the soil. Seed firming wheels press seed into the bottom of the seed trench, improving depth control and seed-to-soil contact. Residue management at harvest in the year prior to no-till or minimum-till seeding is key to success. If crop residue (straw and chaff) is not spread uniformly, seeding equipment cannot operate properly to achieve good seed placement, and seedlings will have difficulty emerging through a mat of residue. Uneven residue distribution also creates an ideal habitat for slugs. No-till canola into cereal residue is not recommended due to risk of stand loss from slugs.

Field Variability

Canola does best on well-drained fields with a minimum pH of 5.5. Fields with variable drainage and pH will have variable stands and yield. Canola performs better on uniform fields. On soils with low moisture holding capacity, spring cereals are more resilient to dry growing conditions than spring canola.

Crop Rotation Considerations

Canola responds to well-drained fields with a minimum pH of 5.5. Crop rotation is the best defence against disease buildup. Rotations of no less than 3–4 years between canola will reduce soil disease build-up. To reduce the incidence of sclerotinia white mould, maintain a 3–4 year rotation with non-host crops.

Rotation is also important to manage herbicide carryover, since canola is particularly sensitive to triazine and ALS (Group 2) products. Carryover will be greater following a dry year and is dependent on soil factors such as pH or organic matter. Environment has a major effect on herbicide persistance. Consult herbicide labels and OMAFRA Publication 75, *Guide to Weed Control.*

Corn should not follow canola in the rotation. Corn roots establish a strong relationship with vesicular arbuscular mycrorhizae (VAM) fungi, which aids in phosphorus uptake. VAM colonization of corn seedlings is diminished when corn follows canola, resulting in increased incidence of phosphorus deficiency.

Site and Rotation Considerations

In addition to the above considerations, establishment and winter survival of winter canola will be most successful where:

- fields have good soil drainage (both surface and sub-surface) so that water never ponds. Root heaving is more common when canola is planted in heavy or poorly drained soils where ice accumulation has occurred.
- good snow cover is available to protect the rosettes from low temperatures and dessication
- moderate climate occurs. Winter canola is slightly less winter-hardy than winter wheat.

Avoid production of canola and tame mustard on the same farm. Winter canola can be controlled in a spring-seeded crop with tillage but may remain as volunteer plants in a no-till situation. Include effective methods of volunteer plant control in your rotation. Do not locate winter canola in areas (i.e., within 5 km) where rutabagas are grown, because both crops are hosts for turnip mosaic virus. Serious crop losses have occurred in rutabagas from this disease. Sporadic problems in the past did occur with winter canola roots entering tile drains in Huron County and areas close to Lake Huron, but not elsewhere. The reasons for this are unclear. Avoid planting winter canola in recently tiled fields and fields where tiles may remain wet all year.

Variety Selection

Winter Canola

New hybrid varieties with improved winter hardiness, improved vigour, black leg resistance/tolerance and high yield potential have allowed winter canola to expand production into more areas of Ontario.

Only import seed that is carrying a phytosanitary certificate (assurance that canola seed is free of blackleg). Blackleg is a serious disease of canola that can be seed- or soil-borne. In the past, importation of seed carrying blackleg caused widespread disease and serious crop losses. Current registered varieties of winter canola have good resistance to blackleg.

Choosing Superior Winter/Spring Varieties

Yield and variety traits for the cultivars tested by the Ontario Oil and Protein Seed Committee are presented in the OMAFRA Infosheet, *Variety Recommendations for Spring and Winter Canola*, available on the OMAFRA website at www.ontario.ca/crops. Select superior varieties that have demonstrated stable yield performance in multi-site, multi-year data.

Aside from yield, other canola traits to consider are:

- lodging resistance
- herbicide system
- disease resistance
- percentage of green and brown seeds

All canola varieties presently being grown in Ontario belong to the *Brassica napus* species (Argentine) and have good resistance to blackleg, although varieties differ in their level of resistance.

Seed Quality Characteristics

Seed quality is important to maintaining a market for canola varieties in Ontario. Brown and green seed (internal colour when crushed) are two important grading factors that affect the oil quality and ultimate market value of the canola. The length of the growing season has the largest impact on brown and green seed, but genetics also plays a role. Consider varieties with a low green and brown seed count.

Planting and Crop Development

Seed Quality

Know the quality of the seed being planted. Germination is the major quality consideration used in grading seedlots. Germination standards test the ability of a seedlot to produce normal seedlings under favourable conditions of 95%–100% humidity and 25°C. Stress conditions in the field following planting often reduce field emergence compared to lab results. Certified seed must meet purity and germination standards.

Seed Treatments

Certified seed is treated with a fungicide and insecticide. The fungicide controls seed-borne and early-season soil-borne diseases, including blackleg, seed decay, damping-off and seedling blight. Insecticide seed treatments contol flea beetles for 2–4 weeks. Slow seedling development may allow flea beetle populations to build after the effectiveness of the seed treatement has declined, requiring a follow-up foliar insecticide treatment (see OMAFRA Publication 812, *Field Crop Protection Guide*).

Spring Canola Seeding Date

Typically, early seeding produces the highest yields. In recent years, some growers report good yields from seeding in mid-May. Consider, though, that flowering generally begins 50–55 days after planting and lasts 10–21 days. Temperature stress (>28°C) during flowering has a greater negative impact on yield than weather at any other stage.

Early Seeding

Seed as early as soil conditions permit. Canola will germinate and grow at a soil temperatures of 1°C, but 10°C is ideal for rapid emergence. Soil conditions and weather forecasts should be the ultimate guide, however 3°C or higher is a reasonable target for planting. Increase seeding rates by 5%–10% when canola is planted very early to account for slower emergence and increased seedling mortality. Canola is slower to establish than cereal crops and is less tolerant to spring frost. When seedlings emerge, the growing point is exposed between the cotyledon (seed) leaves and can be easily killed by a frost. Early planted canola also has a higher risk of infestation by cabbage seedpod weevil during the flowering/early pod stage. If canola growth is slow following planting due to cold weather, flea beatles may become a problem.

Late Seeding

If seeding is delayed, it is critical to conserve soil moisture and to plant into moisture for rapid, uniform emergence. Avoid seeding after June 1st in areas where swede midge has been identified. See *Swede midge* on page 224 or visit the OMAFRA website at www.ontario.ca/crops.

Table 6–1. Amount of Seed Required to Meet Target Seeding Rate

1,000-Seed Weight (gm)	Target Seeding Rate[1] kg/ha (lb/acre)	Seeds /m[1] (/ft)
3.5	3.63 (3.3)	20 (6.1)
4	4.07 (3.7)	20 (6.1)
4.5	4.7 (4.2)	20 (6.1)
5	5.2 (4.7)	20 (6.1)
5.5	5.7 (5.1)	20 (6.1)
6.0	6.2 (5.6)	20 (6.1)

[1] Seeding rate is based on 72% final stand and target population of 75 plants/m^2 (7 plants/ft^2).

Winter Canola Seeding Date

Seed winter canola August 15–30 (in Southwestern Ontario, August 20–September 10). Seeding within these dates results in the canola developing 4–6 leaves and an adequate size root system (approximately 1¼ cm or ½ in. diameter) to reduce the chances of frost heaving and desiccation in the spring. Delays beyond these dates greatly increase the risk of winterkill. If canola bolts in the fall, it will not survive through winter. Heavy competition from weeds or volunteer cereals in the fall can force canola growth, increasing chances of winterkill.

Seeding Rate

The optimum plant stand for canola is 75–130 plants/m^2 (7–12 plants/ft^2). In 19-cm (7.5-in.) rows, this is equivalent to 14–25 plants/m (4.5–7.5 plants/ft) of row. Target seeding rates need to account for large differences in seed size between varieties. Table 6–1, *Amount of Seed Required to Meet Target Seeding Rate*, this page, presents the desired seeding rate for different seed sizes. Increase seeding rates slightly (5%–10%) on soils prone to crusting, when seeding very early or very late.

Seed Bulking

Achieving target canola seeding rates can be a challenge with some drills. Calibrate seeding equipment before heading to the field. Ensure that each of the drill's seed cup openings are set the same. Bulking of seed with pelletized MAP (11-52-0), sulphur or corn cob grits are options for improving seeding rate accuracy. Do not use other fertilizers with canola seed, as this increases the risk of reduced seed germination.

Seeding Depth

Canola seedlings expend a great deal of energy to emerge, making quick, even emergence the goal in seeding. Seed 1.25–2.5 cm (½–1 in.) deep, if there is adequate moisture, and deeper if necessary to plant 0.6 cm (¼ in.) into moisture, but not deeper than 4 cm (1½ in.). If the depth to reach moisture is deeper, it is better to wait for moisture. Press wheels on the drill help place the seed uniformly at the bottom of the seed trench. Drill bounce is more of a problem at speeds over 8 km/hr. Increasing speed affects planting depth. If canola is seeded through the grass seed box, seed tubes should be directed behind openers and in front of the press wheels.

Seeding Conditions

Good seedbed preparation is vital, due to canola's small seed size and shallow planting depth requirements. The seedbed should be level, firm, and crumbly with moisture in the top 2.5 cm (1 in.) of the surface. A crumbly soil will resist crusting after pounding rains, allowing the tiny seedlings to emerge. This is critical, since there is no opportunity to correct crusting. The crust can break the hypocotyl arch (the seedling stem) that lifts the cotyledons (seed leaves) above the soil surface. A firm

Seeding Rate

The seeding rate can be determined by knowing the 1,000-seed weight in grams found on the seed tag and using the following formula:

Metric

Seeding rate (kg/ha)

= (desired plant population/m^2 x 1,000-seed wt. (gm) ÷ seedling survival rate) ÷ 100

Imperial

Seeding rate (lb/acre)

= (desired plant population/ft^2 x 1,000-seed wt. ÷ seedling survival rate) ÷ 10.4

Seedling survival (final stand)

= % germination (on seed tag) x % expected emergence

Sample Calculation

Using seed size of 5 gm/1,000 seeds, 72% final stand

Seeding Rate (lb/acre)

$$= \frac{7 \text{ plants/ft}^2 \times 5 \text{ gm/1,000} \div 0.72}{10.4}$$

= 4.7 lb/acre

Seed Drill Calibration

Collect and weigh (in grams) the seed from a drill opener and use the following formula to convert to lb of seed/acre using a 7.5 in. row width. Check several openers.

Seeding rate (lb/acre)

= gm of seed/opener/30.5 m (100 ft) of travel x 1.54

seedbed will help hold moisture near the surface and aid in uniform planting depth and uniform emergence.

Packing

Let soil conditions determine whether to pack the seedbed before or after seeding. Packing before seeding can help level and firm the seedbed, improving seeding depth control and reducing soil moisture loss. Packing after planting can improve emergence and yield, if the soil dries out before emergence. Packing after seeding may bury the seed deeper if the field was ridged at seeding, thereby reducing emergence.

Broadcast Seeding

Broadcasting of canola seed is a greater risk than seeding with a drill but can still be effective in some situations. Some growers broadcast canola seed with fertilizer onto a prepared seedbed. The advantages of broadcast seeding are higher yield potential because of early seeding date, time savings and low cost. The major disadvantage of broadcast seeding is uneven planting depth and uneven seed application (if uncalibrated). Frost injury is also a risk with an early seeding date. Good seedbed preparation before broadcasting followed by harrowing or packing will keep seed depth constant and ensure good seed-to-soil contact. Despite this, broadcast stands can be inconsistent in dry years. Seeding rates should be higher when broadcast compared to drilled (6–8 kg/ha or 5–7 lb/acre).

Replant Decisions

Generally, canola plants in thin stands will branch out aggressively to compensate, resulting in no significant yield loss. Each year, some fields suffer from thin stands due to poor emergence, frost, insects and diseases. To make a decision, assess the health and plant population of the surviving stand. It is easy to overestimate the extent of the injury and underestimate the ability of seedlings to recover. A uniform stand of 11–22 healthy plants/m^2 (1–2 plants/ft^2) will have a yield that is 90% of a full stand. Assess populations using the hula hoop method to determine plant populations (see Appendix K, *Hula Hoop Method for Determining Plant and Pest Populations*, on page 268).

Plant Development

Spring canola is a cool-season crop that grows best at temperatures above 10° C and below 30° C (optimum 20°C–25°C). Crop development is closely related to the amount of sunshine received, although temperature also is a factor.

Table 6–2. Approximate Growing Degree Days to Reach Various Stages of Development

Growth Stage (decimal code system)	Description	Growing Degree Days (Base 0°C)[1]
0–1.0	Emergence	152–86
1.1–1.2	1–2 leaf stage	282–324
1.4–1.6	4–6 leaf stage	411–463
3.0–4.0	Bud–first flower	582–666
4.9	Late flower	759–852
8.1	Maturity[2]	1,432–1,557

[1] Adapted using research data from AAFC, Scott and Swift Current.

[2] Occurs when seed begins to mature, 10% seed colour change.

Development of canola is more closely aligned with growing degree days than crop heat units, similar to that of spring wheat. Canola matures in approximately 90–100 days in southern growing areas, and 110–120 days at New Liskeard. In northern growing regions, longer day length can partly compensate for lower temperatures. Drought and heat stress will shorten the days to reach maturity. The approximate GDDs to reach various stages of development is presented in Table 6–2, *Approximate Growing Degree Days to Reach Various Stages of Development*, this page. High temperatures at flowering cause flower and pod abortion. Maturity differences among varieties is typically less than 7 days.

Principal Growth Stages of Canola

Rosette

Germination of canola is similar to other dicots — seedlings emerge with the growing point contained between cotyledons (seed leaves). A 5–6-leaf rosette forms, with larger, older leaves at the base and smaller, younger leaves developing in the centre. Leaf area development is directly related to growth rate and final yield.

Stem Elongation (Bolting)

Lengthening days and rising temperatures trigger bud formation in the centre of the rosette and the stem rapidly "bolts". The main stem reaches 30%–60% of its final height at the start of flowering. A large leaf area (especially upper leaves) at this stage strongly influences pod set and final yield.

Flower

Flowering begins with the opening of the lowest bud on the main stem and continues upward on both main and secondary branches. Flowering continues for about 14–21 days.

Table 6–3. Nitrogen Recommendations for Spring Canola

N:Canola Price Ratio ($/kg N:$/kg canola)	Recommended N Rate (kg/ha)
2	119
2.5	108
3	96
3.3	90
3.5	85
4	74

100 kg/ha = 90 lb/acre

To use this table, the price of canola must be known or estimated. Canola at $450/t and nitrogen at $1.50/kg results in a price ratio of 3.3 (1.50/0.45). At these prices, use 90 kg/ha of nitrogen.

Fertilization occurs within 24 hours of pollination. The maximum plant height is reached at peak flowering. Typically, flowering begins 50–55 days after planting (582–666 GDD). Temperature stress (>28°C) during flowering causes flower abortion and is detrimental to yield at this stage (Plate 33 on page 284). Canola can either self-pollinate or cross-pollinate, depending on various environmental factors.

Ripening

The leaf, stem and especially pod surface area are major food sources for the developing seed. Seed filling is complete about 30–40 days after flower opening. Pod ripening occurs from bottom to top of the plant. When seeds have turned green, leaf senescence begins, and the pod wall becomes the major source of food, although the stem is also important. When 30%–40% of seeds on a plant have started to change colour, seed at the top of plant will be nearly mature, and the average seed moisture will be 30%–35%.

Fertility Management

Placement and Timing

Most fertilizer for canola is broadcast. The high rates of nitrogen required and the seeding methods used work against the use of fertilizers banded with the seed. There may be occasions, particularly where phosphorus soil-test levels are low, when phosphorus application with the seed would be advantageous. Take care not to exceed safe rates.

The rate of nitrogen fertilizer placed with the seed must not exceed 11 kg/ha (10 lb/acre). Place only superphosphate or monoammonium phosphate (MAP) with the seed.

Table 6–4. Spring Nitrogen Requirements for Winter Canola

Price Ratio[1] ($/kg N:$/kg canola)	Expected Yield t/ha[2]		
	2	3	4
	Most Profitable Nitrogen Application (kg N/ha)[3]		
3.3	125	170	195
2.5	160	195	210
2.0	180	210	220

100 kg/ha = 90 lb/acre

[1] To use this table, the price of canola must be known or estimated. Canola at $450/t and nitrogen at $1.50/kg results in a price ratio of 3.3 (1.50/0.45). At these prices and an expected yield of 3.0 t/ha, use 170 kg/ha of nitrogen.

[2] 1 t/ha = 893 lb/acre.

[3] Where manure is applied, reduce the fertilizer according to the amount and quality of manure (*Manure*, on page 164).

Nitrogen

Spring Canola

Canola has a great demand for nitrogen. The nitrogen fertilizer recommendations for canola in Table 6–3, *Nitrogen Recommendations for Spring Canola*, this page, are based on the price ratio between canola and nitrogen fertilizer. Rates should be adjusted downward if manure was applied or if the previous crop contained legumes such as alfalfa (see Table 9–7, *Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down*, on page 162, and Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page 164). Excessive nitrogen in the soil has been linked to green seed problems.

Winter Canola

Fall Application

Apply up to 40 kg/ha (36 lb/acre) of nitrogen in the fall. If the land was fallowed for one or more months before planting or if forage legumes were plowed down or manure applied before planting, no nitrogen fertilizer should be applied.

Spring Application

The rate for spring application of nitrogen is based on the expected yield and on the price ratio between canola and nitrogen fertilizer. See Table 6–4, *Spring Nitrogen Requirements for Winter Canola*, this page.

Table 6–5. Phosphate and Potash Recommendations for Canola Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating[1]	Phosphate (P_2O_5) Required (k/ha)	Ammonium Acetate Potassium Soil Test (ppm)	Rating[1]	Potash (K_2O) Required (kg/ha)
0–3	HR	70	0–15	HR	70
4–5		60	16–30		50
6–7		50	31–45		40
8–9		30	46–60		30
10–12	MR	20	61–80	MR	20
13–15		20	81–100		20
16–20	LR	0	101–120	LR	0
21–25		0	121–150	RR	0
26–30		0	151–180		0
31–40	RR	0	181–210		0
41–50		0	211–250		0
51–60		0	251+	NR[2]	0
61+	NR	0			

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR, and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] A rating of "NR" may mean reduced yield or quality of the crop if fertilizer is applied.

Phosphate and Potash

Phosphate and potash recommendations for canola are given in Table 6–5, *Phosphate and Potash Recommendations for Canola Based on OMAFRA-Accredited Soil Tests*, this page. For information on the use of this table or if a soil test is unavailable, see *Fertilizer Recommendations*, on page 158.

The phosphorus requirement for canola is greater than for cereals, due to the higher protein content of the seed. A 2.5 t/ha (1 ton/acre) canola crop will remove an average 66 kg/ha (59 lb/acre) of phosphate fertilizer (P_20_5). During germination and emergence, canola is sensitive to fertilizer salts. Salt injury can substantially reduce stands. Canadian research suppots an initial 11–17 kg/ha (10–15 lb/acre) of starter phosphate. The highest response can be expected when planting into cool soil conditions on soils with low-to-medium fertility levels.

Nutrient Deficiencies

Sulphur

Canola requires twice as much sulphur compared to cereal crops. Soils in Southern and Northeastern Ontario generally have adequate sulphur for optimum yields, either as native soil sulphur or from atmospheric deposition. Trials have shown no consistent response to sulphur containing fertilizers in Southern or Northeastern Ontario. There have been scattered instances of sulphur-deficient soils with low organic matter in Northwestern Ontario. Deficiency symptoms are a general yellowing of the entire plant, mottling of leaf surface, purple underside of leaves and small, pale yellow flowers (Plate 30 on page 283).

Soil testing is not a reliable way to assess sulphur availabilty to crops, since sulphur content changes rapidly. Plant tissue testing can be useful where sulphur deficiency is suspected. Where required, sulphur can be supplied by replacing some urea with ammonium sulphate to supply the same amount of N. Elemental sulphur is not available to plants until it has oxidized to the sulphate form, a process that can take 12–18 months.

Boron

Boron deficiencies are rare in canola, although there have been some plots that have shown positive yield responses to foliar applications of boron. Symptoms include seed abortion, misshapen pods and narrow, strap-like leaves. It is rarely seen, but when it occurs, it can significantly reduce yields. Boron deficiency can be corrected with either foliar or soil applications of soluble boron fertilizers.

Harvest and Storage

Direct combining is the most common method of harvest, although swathing is used in some areas. Direct combining usually results in improved seed quality compared to swathing, due to fewer fines and less green seed. For more information on harvesting, see the Canola Council of Canada "Harvest Management" section of the *Canola Growers Manual* publication (www.canola-council.org).

Direct Harvest

Direct combining is most successful when the crop ripens evenly, is relatively free of *Alternaria* disease, is heavy, partially lodged and well knitted together. These conditions reduce the risk of shelling and pod drop due to wind. For direct-harvested canola, the crop is ripe when the pods rattle if shaken. Some varieties are less prone to shattering and are well suited to direct combining. If the crop maturity is uneven, the need for, and cost of, using a desiccant should be evaluated versus swathing the crop. Seed oil content tends to be higher when a crop is direct harvested. Harvesting in the direction of the lean will significantly reduce shatter losses.

Swathing

The optimum stage to swath canola is when 50%–60% of seeds on the main stem have changed colour. Farms with large areas of canola should start swathing at 30% colour change to ensure that the majority of acres can be swathed at near-optimum maturity without the risk of over-ripening and shelling. Canola ripens and dries quickly in the swath. Usually 5–10 good drying days will lower the moisture so that seeds in the upper pods are firm. Canola seed can drop by 1% moisture or more per hour in the swath.

Seed colour change is a better indicator of maturity than pod colour or overall colour of field. In staging maturity, examine only those pods on the main stem. When 30%– 40% of seed has started to change colour from green to yellow-brown, overall moisture content will be 30%. The pods at the bottom of a canola plant ripen first, therefore the pods at top may still be greenish when the field is ready for swathing. Do not let premature ripening caused by *Sclerotinia* or *Alternaria*, influence optimum stage to swath. Most of the crop yield will come from healthy plants. Pick a point at which the majority of the field is at correct stage, ensuring that in less mature areas that seeds are green, firm and no longer translucent. It often helps to swath when the crop is moist with dew or during a light drizzle. The stubble should be left tall enough, about 25–30 cm (10–12 in.) to support the swath (and minimize combine wear).

To learn more about proper field assessment, see the Canola Council publication *Canola Time of Swathing Guide* or visit the website at www.canola-council.org/pub_swathing.html.

Pre-Harvest Herbicides to Assist Canola Harvest

A pre-harvest herbicide application can facilitate direct harvest by speeding up dry-down of canola plants and weeds to allow for timely harvest and reduce dockage from green seeds. Application can be helpful if the crop is uneven, reducing the risk of shattering in mature plants while waiting for immature areas to dry down. Application will speed up dry-down, but not plant maturity. Harvest the field as soon as the crop is ready, as further dry-down increases risk of shattering loss. If winter wheat is planned and perennial weed pressure is high, a pre-harvest burn-down may be the best option for weed control, since there isn't enough weed top growth for effective control after harvest. Glyphosate applied to Roundup-Ready canola will assist with dry-down of weeds and control of perennial weeds, but it will not help to dry down the crop.

Combining Canola

The optimum time to harvest canola is when there are few green seeds and seed moisture content is less than 10%. Do not delay harvest as seed loss due to shatter increases dramatically approximately 10 days after optimum harvest timing. Depending on weather conditions, seeds rapidly lose moisture at 1%–3% or more per day. Shattering losses can be reduced by combining at higher seed moisture content and drying the crop, harvesting when there is a dew or harvesting at night. Many operators start combining when the seed is slightly above 10% moisture. Check green seed content, to harvest a quality sample. Based on crushed seed examination, No. 1 and No. 2 Canada canola grades may contain a maximum of 2.0% and 6.0% distinctly green seeds, respectively.

Hot or windy weather can result in seed at a moisture content that indicates it is ready for combining, before there has been sufficient time to clear itself of green chlorophyll. Several dews or a light rain can help seed to clear the green colour. Monitor and make adjustments throughout the day to minimize harvest losses. Average harvest losses range from 10–50 kg/ha (9–45 lb/acre). A loss of 1 kg/ha equates to about 54 seeds/m^2 (5 seeds/ft^2) on the ground.

For further information on drying, handling, and storage of canola, see *Storage of Canola* on the Alberta Agriculture website at www1.agric.gov.ab.ca/.

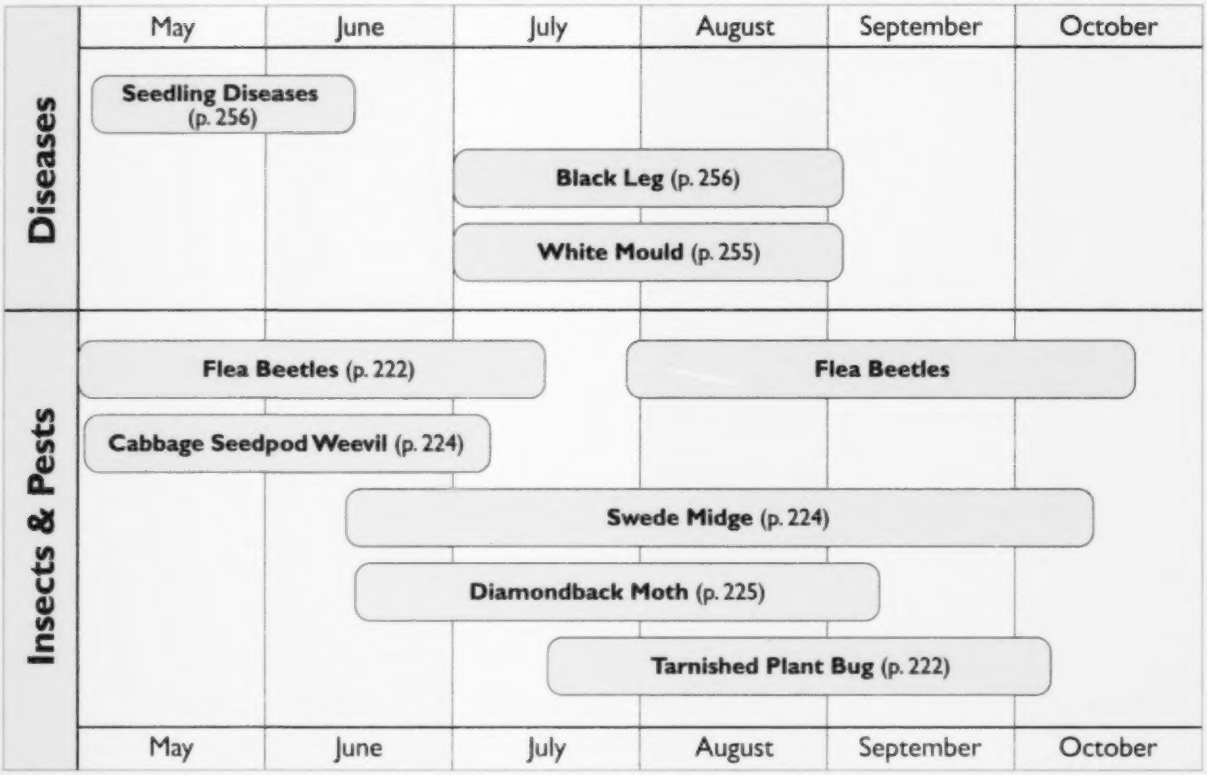


Figure 6–1. Canola Scouting Calendar

Other Crop Problems

Insects and Diseases

Figure 6–1, *Canola Scouting Calendar*, this page, shows insects and diseases that could be causing symptoms in the field. Individual descriptions of insects and diseases, scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, and Chapter 14, *Diseases of Field Crops*.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

Frost

Canola seedlings can recover from a light spring frost if the growing point is not damaged. Prior to taking any action, wait 4–5 days to assess damage. Check the growing point for green colour at the centre of the leaf rosettes (Plate 31 on page 284). Although the cotyledons or other leaves may be black, re-growth can occur in 4–10 days, depending on weather conditions.

Seedlings are more tolerant of frost at the 3–4-leaf stage than at the cotyledon stage. Ice crystals can form on the surface of plants without necessarily causing serious damage. Water within plant cells contains dissolved products that lower the freezing point by several degrees over water outside the cell. The length of time the plant is exposed to freezing temperatures is important, since a sharp frost that lasts only a short period may cause less damage than a mild frost that lasts all night. Rapidly growing plants are less tolerant of frost than plants that have undergone several days of cold weather (hardening).

Frost can be more damaging to canola that is in the flowering stage. Although pollination may not be affected, seeds that have begun to develop about a week prior to pollination will be affected by several hours at freezing temperatures (–3°C to –4°C). These freezing temperatures can also reduce seed fill. Check pods for damaged seeds that have lost their green colour and turgidity (Plate 32 on page 284).

Hail Damage

If hail removes both cotyledons or the stem is broken below the cotyledons, plants usually do not survive, but the yield impact will not be as large as the loss of plants. If hail occurs during vegetative growth, yield loss will be dependent on the amount of leaf area destroyed. Yield loss will equal approximately 25% of the leaf area destroyed. Stem bruising and breakage will result in higher losses.

Table 6–6. Percentage Yield Loss Due to the Destruction of Branches During Flowering in Canola

% Branches Lost	Days From First Flower				
	–7	0	7	14	21
	Percentage Seed Yield Loss				
10	0	0	10	10	10
20	0	0	13	20	20
30	0	0	12	29	30
40	0	0	12	32	40
50	0	0	14	36	50
60	0	0	18	42	60
70	0	0	24	50	70
80	0	5	31	60	80
90	0	12	40	71	90
100	0	20	51	84	100

Source: Canola Council of Canada, 1994.

Research conducted in Western Canada.

If hail occurs during flowering, plants can compensate by developing secondary clusters and new branches (see Table 6–6, *Percentage Yield Loss Due to the Destruction of Branches During Flowering in Canola*, this page). Yield losses will be highest when hail occurs during late flowering and during pod fill. Canola has poor ability to recover from hail once the pod-fill stage is reached. Expect that hail between flowering and pod fill will result in uneven maturity as a result of a later flush of growth or flowers.

Brown-Seed (Heat Damaged)

Brown-seed has been an occasional problem in some years. Brown-seed refers to the brown internal colour of the seed when crushed and is caused by premature abortion of the developing cotyledons. Brown seeds are produced when canola is subjected to extended periods of high temperatures and moisture stress due to dry conditions, during pod fill. High levels of brown-seed may not be suitable for processing for the food market because of much higher free fatty acids (FFA) and phosphorus levels. High FFAs occur when the oil in the seed breaks down. This results in unstable oil that is subject to more rapid rancidity. There is limited research that suggsts that brown seed is increased by insect feeding on developing seeds by tarnished plant bug or lygus bug and cabbage seedpod weevil. Registration of new varieties requires the FFA levels to be lower than those of current varieties.

Green Seed Problems

Green seed is an important grade determinate with Grade #1 canola containing a maximum 2.0% green seed. Green (immature) seeds are distinctly green when crushed. Green seed occurs when chlorophyll becomes "locked in" the seed at harvest. Causes include:

- early frost
- swathing or direct harvesting too early
- uneven crop maturity
- variety
- hot, very low humidity during ripening

Natural plant enzymes break down chlorophyll as seeds mature. Air temperature and seed moisture is important in the breakdown of chlorophyll. When seed moisture drops below 20%, enzyme activity and seed respiration slows, reducing the rate at which green seed clears. Green seed that is stored at correct safe moisture levels (<10%) will not show any reduction in green seed content . A sub-lethal frost (about 0°C to –10°C) can slow and even reverse the enzyme activity that breaks down chlorophyll. The main effect of a frost is that it causes a rapid dry-down of pods and seeds before the chlorophyll has a chance to clear. Thin stands result in more branching of plants and an increase in variability in seed maturity.

Winterkill

Winter canola is less winter-hardy than winter wheat in Ontario. Winterkill is most common in March and April after winter canola loses its winterhardiness, begins to grow and then is damaged by a return to extremely cold temperatures. Winterkill can also result from a lack of winter snow cover, prolonged periods of ice cover and desiccation by winter winds, resulting in weakened stands.

Heaving is an issue where there is not sufficient snow cover into late March–April when freeze-thaw cycles cause heaving, particularly on poorly drained soils. Small plants that did not become adequately established lack the lateral roots necessary to anchor the plant against heaving. In saturated soils, freeze thaw cycles can damage the top portion of the taproot, allowing root rot to invade. Plants that heave by more than 4 cm (1.5 in.) often don't survive.

If the damage is severe enough (75% kill), the crop may not be salvageable. However, if 30% of the stand remains, with healthy plants evenly distributed across the field, the crop will compensate sufficiently.

Cross-Pollination

If varieties with different herbicide-resistant traits are allowed to cross-pollinate, the result may be volunteer plants with multiple resistance traits in subsequent crops. Separate fields planted to varieties resistant to different herbicides by a minimum of 175 m. This isolation will reduce the occurrence of field-to-field cross-pollination. Research at AAFC, Swift Current, has indicated that pollination contamination was 2.1% at 46 m (150 ft), 1.1% at 137 m (450 ft) and 0.6% at 366 m (1,200 ft).

A more recent study found that the first 100 m (330 ft) of an adjoining field contained about 99% of the unwanted pollen.

7. Other Crops

Buckwheat

Buckwheat is a fast-growing summer annual with broad, heart-shaped leaves and white flowers. It takes approximately 10–12 weeks from planting to harvest. Buckwheat is frost sensitive and is usually planted later than other field crops.

Buckwheat is used for human consumption, as an ingredient in livestock feeds and as a source for buckwheat honey. It is also commonly used as a cover crop for weed suppression and green manure (see *Cover Crops*, on page 146). The grain of buckwheat has an amino acid composition that includes lysine and thus provides a more complete protein compared to other cereals.

The most lucrative market is for the export of quality, large-seeded buckwheat to the Pacific-Rim countries, particularly Japan.

Tillage Options and Seedbed Preparation

Frequently, buckwheat is planted in abandoned fields, old pastures or other land that has been neglected for years. When preparing the seedbed, aim for effective weed control, conservation of moisture and a firm seedbed. If the field was plowed in the fall, disk the soil in early spring, then disk or cultivate it approximately 2 weeks later to kill weeds. Repeat this sequence until seeding time.

Spring plowing is also an option, however, be sure to plow as shallow as possible. To improve the soil condition and destroy weeds, work the soil every 7–10 days until seeding time. Shallow tillage minimizes new weeds coming to the surface and conserves moisture. Harrowing should leave the field ready for seeding.

If a hay or pasture is plowed in late-June or early-July, buckwheat can follow and be used as a cover crop to control weeds or to act as a green manure.

Field Selection

Buckwheat grows best on light-to-medium-textured soils but will grow on a wide range of soil types, producing a better crop on poor soil than any other grain. Buckwheat prefers well-drained soils with a pH of 5.0 to 7.0. It is intolerant of severely dry, saturated or compacted soils.

Buckwheat is adapted to a cool, moist climate but will also grow well during warm weather. It is sensitive to high temperatures and hot, dry winds. If these conditions occur during flowering, seed-set and yield will be reduced. Buckwheat is susceptible to late-spring and early-fall frosts and requires 10–12 weeks to reach maturity.

When growing buckwheat for seed, avoid planting in fields where other grains were previously grown, in order to reduce volunteer grain. This problem can be overcome by tilling in the fall and planting a winter cover crop that is incorporated in the spring before planting the buckwheat.

Weed control options in buckwheat are limited, so best yields will be obtained from clean, weed-free fields.

Avoid fields that contain very high levels of nitrogen, since this can cause crop lodging. Often the lush growth associated with fields high in nitrogen has led to a higher incidence of white mould. White mould is a problem in soybeans, canola, sunflowers and buckwheat. If possible, avoid fields where white mould has been a problem.

Variety Selection

If the crop is being grown for export markets, variety selection becomes important. The Japanese, North American and European markets demand large-seeded varieties for milling and de-hulling purposes. Mancan is one popular variety that has a thick stem and medium height characteristics, which makes it more resistant to lodging.

New varieties tend to have larger seed size, along with increased bushel weight. These large-seeded varieties have larger leaves and, as a result, do not require higher seeding rates than the smaller-seeded types.

For seed sources, see *Cover Crop Seed Suppliers* on the OMAFRA website at www.ontario.ca/crops.

Planting

Buckwheat will germinate at temperatures anywhere between 7°C and 40.5°C, so the planting date can be any time after the risk of frost has passed.

Yields are highest if buckwheat is planted immediately after the risk of frost has passed. Where possible, try to avoid flowering in the very hot weather of mid-summer. Early plantings help minimize volunteer problems the following year. However, in cold springs, some have experienced more weed problems with early plantings. In a cold spring, planting should be delayed until conditions are more favourable for crop emergence.

Traditionally, buckwheat was planted in mid-summer and often combined after frost. Although this method avoids flowering during hot weather, dropped seed reduces yield and poses a severe volunteer problem for the following crops.

Planting seeds with a grain drill will produce a more even stand, but satisfactory results can also be obtained with broadcast seeding. Plant seeds at a depth of 4–6 cm (1½–2½ in.), into moist soils. Place seed only deep enough to reach consistently moist soil, to obtain rapid and uniform emergence. Seedlings should emerge in 2–5 days.

Recommended seeding rates for seed production are 50–65 kg/ha (45–60 lb/acre), which is equivalent to 1–1.25 bu/acre. This will achieve the ideal plant stand of 140–183 plants/m^2 (13–17 plants/ft^2).

When planting buckwheat for a green manure crop, the optimum seeding rate ranges from 54–108 kg/ha (1–2 bu/acre). Higher seeding rates result in higher plant populations, producing a smothering effect for weed control. However, even if the stand is thin, the plant's ability to branch out will often compensate for the thinner stand and will still result in good weed control. When using the higher seeding rate, divide the seed in half and cross-plant the field with the grain drill. This appears to give better spacing of plants with fewer tall, thin stems and subsequent lodging problems.

Flowering begins 5–6 weeks after sowing and continues for at least 1 month. There are three flower sets with buckwheat. Insects, honeybees and leafcutter bees are the main pollinating agents and are essential for good seed set. An arrangement with an apiarist will be of mutual benefit.

As a Green Manure

Buckwheat has the reputation of using phosphate unavailable to other crops, thereby increasing the amount of phosphorus available to following crops. To take advantage of its large biomass, buckwheat is incorporated between 4 and 7 weeks after planting, before the first seeds have set. It is disked down at 10% bloom and left on the surface for a few days to dry. When plants start to crinkle when stepped on, it is time to disk them into the soil. If the field is left until full bloom, there is more likelihood of volunteer problems the following year. A second or even third planting may be possible in long growing seasons.

Table 7–1. Nitrogen Requirements for Buckwheat

Growing Region	Maximum Rate of Nitrogen for Buckwheat (kg/ha)
Southern Ontario	35
Northern Ontario	55

Fertility Management

Fertility requirements for buckwheat are similar to oat. Table 7–1, *Nitrogen Requirements for Buckwheat*, this page, and Table 7–2, *Phosphate and Potash Recommendations for Buckwheat and Flax Based on OMAFRA-Accredited Soil Tests*, opposite page, display the recommended rates of nitrogen, phosphate and potash based on OMAFRA-accredited soil tests.

Caution:
Buckwheat is prone to lodging with high soil nitrogen.

Harvest and Storage

Harvest

Buckwheat is an indeterminate plant. Flowers, green seed and mature seed are present on the plant at the same time. Harvest must occur prior to the development of overripe seed. This will be approximately 10 weeks after planting. At this time, the crop is still growing and flowering. However 70%–75% of the seeds should be brown and mature and not yet dropping from the bottom of the bloom spike. If harvest is delayed until the seeds nearest the ground begin to fall, yields will be decreased due to seed dropping, and the volunteer population will cause problems for the next crop. Yields will vary depending on pollination and weather conditions. Yields of 2.2 t/ha (40 bu/acre) are possible, but 1.1–1.6 t/ha (20–30 bu/acre) are more commonly reported.

Desiccation weakens the stem and causes lodging. Do not desiccate buckwheat. Swathing should be done before combining if the crop has not been killed by frost. Swathing is best done early in the morning when the dew is present or in damp weather to help minimize losses due to shattered seed. Cut the buckwheat, leaving a high stubble to facilitate drying. Leave it to dry until moisture in the seed head reaches 16%.

When combining, reduce the pick-up speed to match the ground speed to minimize shattering. The draper-type of pick-up causes less shattering than the drum-type. To minimize breakage, reduce the cylinder speed to one-third (600–800 rpm) of that used for cereal

Table 7–2. Phosphate and Potash Recommendations for Buckwheat and Flax Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating[1]	Phosphate (P_2O_5)[2] Required (kg/ha)	Ammonium Acetate Potassium Soil Test (ppm)	Rating[1]	Potash (K_2O)[2] Required (kg/ha)
0–3	HR	70	0–15	HR	70
4–5		60	16–30		50
6–7		50	31–45		40
8–9		30	46–60		30
10–12	MR	20	61–80	MR	20
13–15		20	81–100		20
16–30	LR	0	101–120	LR	0
31–60	RR	0	121–250	RR	0
61+	NR[2]	0	251+	NR[2]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrients. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] No expected agronomic response from additional application of nutrients. Ratings of "NR" may result in reduced yield or affect nutrient balance in crops. For example, additional phosphorus application to a soil >60 ppm phosphorus could induce a zinc deficiency on soils low in zinc and might also increase the risk of phosphorus movement to surface water, while additional potash application to a field already >250 ppm K soil test could induce magnesium deficiency on soils low in magnesium.

grains and set the concaves to approximately 13–16 cm (5¼–6½ in.) in the front and 9 mm (⅜ in.) in the rear. The upper sieve is set at 16 mm (⅝ in.) and the lower sieve at 8 mm (5/16 in.). If seed is dehulling, increase the concave size or lower the cylinder speed. The lower sieve can then be opened gradually to the setting that does not allow excess foreign material to pass through. Check that the wind blast is strong enough to remove the maximum amount of trash without blowing out clean grain.

When using a summer planting system, wait until 7–10 days after a light fall frost before direct combining. Keep the cut as high as possible and ground speed low to prevent overloading the combine. To reduce breakage, pay attention to the amount of coarse material that is allowed to pass through so that only a minimum of seed enters the return.

Storage

A moisture content of less than 16% is needed for safe storage. The Japanese market buys only freshly harvested buckwheat, so do not store seed to sell the following year and do not mix old and new crops. It is easy to detect the difference between previously stored and newly harvested buckwheat by the colour of the grain just under the hull. Old seed oxidizes, and the light green layer just under the hull in new seed gradually changes to reddish-brown during storage.

Livestock Feed

Buckwheat grain can be used for livestock feed on a limited inclusion in the ration. Buckwheat grain can be up to one-third of the grain concentrate portion of the beef or dairy ration. More recent swine feeding research with newer varieties of buckwheat found that the overall performance of growing-finishing pigs was comparable to pigs fed cereal grains. However, the price of buckwheat makes this less economical compared to feeding cereals.

Caution

Feeding buckwheat fodder, whether fresh or dried, can have toxic effects. The primary effect is a photosensitization in animals with light-coloured skin (this includes cattle, goats, sheep, swine and turkey) exposed to the sun. Jaundice is a secondary toxic effect.

Weed Control

Weed control in buckwheat can be difficult and requires planning, since there are few herbicides available, particularly for broadleaf weed control. Since buckwheat is sown late, there is ample opportunity to control problem weeds with herbicides or cultivation before seeding. Do not use residual herbicides (i.e., residues from the triazine, sulfonylurea and trifluralin herbicides) before seeding.

Insects and Diseases

Buckwheat seldom has insect or disease concerns.

Flax

Flaxseed has many uses. Its major use has traditionally been in oil-based paints and other protective coatings but it is also used in such things as linoleum, printer's ink, soaps, putty, industrial lubricant and as a salt-resistant coating for concrete highways and sidewalks. Flaxseed contains 35%–40% linseed oil. After oil extraction, the remaining linseed meal is used as a livestock protein supplement, averaging approximately 35% protein content. The addition of flax or flax byproducts in a variety of foods has diversified this market.

In recent years, the acreage of flax grown for oilseed markets has been quite limited in Ontario due to a lack of local crushing facilities. In the early 1950s, Ontario grew over 30,000 ha (74,100 acres) of flax but this has been reduced to less than 1,000 ha (2,470 acres) during the last decade. More recent promotion of the health benefits of flaxseed and of potential export markets for fibre flax may allow for a resurgence of this crop in Ontario in some areas. More information on this crop in Canada is available from the Flax Council of Canada website at www.flaxcouncil.ca.

Unless otherwise stated, the recommendations given here refer to oilseed-type flax. Recommendations for fibre flax may be different, and more research may be needed for that crop.

Tillage

Conventional tillage is preferred. In most cases, this has been fall primary tillage followed by early spring tillage and planting. Secondary tillage should be shallow to set up a firm level seedbed. Packing either before or after planting is recommended. Crop success to date has been better where surface crop residues are low. Some growers have experimented with no-till planting with some success. Use rotations similar to those for cereals or legume forages.

Variety Selection

Variety selection will be different for oilseed markets than for fibre purposes. Until now, oilseed varieties have been the only commercially produced flax grown in Canada. Oilseed varieties are grown specifically for the oil extracted from the seed.

Solin is a new oilseed developed from flax using advanced crop-breeding techniques. Solin oil contains less than 5% linolenic acid (compared to the more than 50% contained in flaxseed oil), producing a light oil suitable for cooking. Canadian Grain Commission Standards specify that Solin varieties must have a yellow seedcoat.

Currently there are no organized flax variety trials in Ontario, however flax and Solin variety-trial results from Western Canada are available from the Flax Council of Canada website at www.flaxcouncil.ca.

Planting

Flax is planted using similar equipment to cereals, in narrow rows (15–20 cm or 6–8 in. apart). Using a grain drill usually results in a more even seeding depth and plant emergence than broadcast seeding. Seed to a maximum depth of 2.5 cm (1 in.), as there will typically be more than enough soil moisture to stimulate germination in the spring. Deep seeding can significantly delay emergence, particularly during cool, wet springs. Optimum seeding rates are 35–50 kg/ha (31–45 lb/acre). Seeding rates higher than 50 kg/ha (45 lb/acre), along with high nitrogen rates, can lead to excessive lodging, making harvest difficult.

Sow as early as possible in the spring on a dry, firm seedbed. Early planting results in higher yields and makes the crop easier to harvest. Well-drained loam, silt loam or clay loam soils are preferred. Performance has been found to be poorer on sandy soils due to a limited root system that is susceptible to moisture stress during dry conditions because of a relatively short taproot. Generally, seedlings can withstand moderate frost.

Crop Development

Flax is an annual plant with a short taproot from which fibrous roots grow to depths of approximately 1.2 m (4 ft) in light soil. The height of the crop varies from 45–91 cm (18–36 in.), depending on growing conditions. In thick stands, only a main stem develops but in thin stands four or more tillers can be produced. Flowers may be white, blue, pink or violet, depending on variety. Flowers open late in the morning and drop by early afternoon. Flax flowers for 3 weeks or more if sufficient nutrients are present. Its flowers can self-pollinate, but insects can cross-pollinate between varieties. A seed capsule produces up to 10 seeds ranging in colour between reddish or deep brown to smoky yellow. The seed has mucilaginous material, giving it a sticky texture when wet.

Fertility Management

Flax recommendations for nitrogen are the same as for mixed grain (45 kg/ha or 40 lb/acre in Southern Ontario and 70 kg/ha or 62 lb/acre in Northern Ontario). Excessive nitrogen will make the crop lodge. A soil test is the best method of determining fertilizer requirements. See Table 7–2, *Phosphate and Potash Recommendations for Buckwheat and Flax Based on OMAFRA-Accredited Soil Tests*, on page 131. Flaxseed is susceptible to fertilizer burn, so all fertilizer should be broadcast.

Harvesting and Storage

Harvest

Flax typically yields about 1,200–2,000 kg/ha (1,100–1,800 lb/acre). Flaxseed can be harvested by either direct combining or by swathing prior to combining. Since flaxseed will continue to produce new vegetation throughout the season, a preharvest dessicant will be needed if the crop is being direct combined. Typically, growers will use glyphosate for this purpose. Consult the product label for specific directions on pre-harvest applications. Swathing, then combining, results in drier seed than direct combining. Swathing should be done when approximately 90% of leaves have fallen off, and the seeds have turned dark brown. Flaxseed doesn't shatter as easily as other grains. Weedy crops should be swathed to allow weeds and straw to dry out before harvest. Leave 15 cm (6 in.) of straw stubble in the field to keep windrows off the ground. Under good drying conditions, the crop can be combined 3–4 days after swathing.

Keep combine and swather cutter bars and guards sharp so as to reduce the accumulation of immature flax straw on the knife. Combine flax when the straw is dry and seeds rattle in the boll. Early-sown flax is easier to thresh than late-sown flax because it has drier conditions to dry in before being harvested. Batt reels should be used when direct combining, because the pick-up reels cause problems with wrapping.

The general recommendation for combine adjustment is to close up the clearance between the cylinders and concave to about half that of cereal grains and slow down the cylinder. Fan speed settings should be fairly low as seed is easily blown out the back of the combine. A clean-looking sample in the bin is an indication that too much seed is being blown out. It is not unusual to have dockage levels of 5%–10%. Be sure to plug any holes in the grain tank, augers and elevators, because flax seed is extremely slippery and will flow through small holes.

Storage

Flax is not normally stored on the farm but is shipped immediately after harvest. Optimum moisture is 10.5%. Higher moisture percentages will incur a drying and shrinkage charge. Proper storage is critical, since flax can spoil quickly. Storage bins must have all holes repaired, because flax can leak through very small openings. Remove green weeds and weed seeds to reduce the amount of dockage.

Straw Removal

Oilseed varieties of flax straw are not suitable for linen production because of the short fibres in the stem. The flax straw is slow to rot in the soil and is usually a problem for tillage operations following harvest or in the following crop season. Make every effort to find a use for the straw so that it can be taken off the field. Flax straw is sometimes used in feedlots as bedding. The straw has also been used as a heat fuel source when burned in large furnaces.

Weed Control

Flax is a poor competitor with weeds. Flax does not form a dense canopy to shade the ground, so weeds have a chance to establish. Plant flax in relatively weed-free fields whenever possible. Do not plant flax in fields with tremendous perennial and "problem" weeds, as herbicide options to control such species are limited.

For herbicide options and recommendations, see OMAFRA Publication 75, *Guide to Weed Control.*

Insects and Diseases

Insects and diseases are typically not a concern in flax production.

Sunflower

Sunflowers have been grown in Ontario for several decades. The main market for Ontario sunflowers has been the birdseed and confectionery markets. Both black seeded and striped sunflower seeds are sold into the birdseed markets. There are no sunflower oilseed crushing markets in Ontario. Acreage in Ontario has varied from 500–1,000 ha (1,235–2,470 acres) per year during the past 10 years.

Tillage

Sunflowers require a firm, moist seedbed that is weed free. Conventional tillage is usually preferred over no-till, as the tillage is beneficial to control weeds.

The best crop performance is usually on medium-textured soils that are naturally well drained: loam, silty loam or silty clay loam. Sunflowers can also grow well on sandy soils, but yield will be reduced under moisture stress during dry conditions. Avoid poorly drained soils as they will delay planting, slow the rate of growth and cause a higher risk of disease.

Table 7–3. Phosphate and Potash Recommendations for Sunflowers Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating[1]	Phosphate (P_2O_5) Required (kg/ha)	Ammonium Acetate PotassiumSoil Test (ppm)	Rating[1]	Potash (K_2O) Required (kg/ha)
0–3	HR	110	0–15	HR	170
4–5		100	16–30		160
6–7		90	31–45		140
8–9		70	46–60		110
10–12	MR	50	61–80	MR	80
13–15		20	81–100		50
16–30	LR	20	101–120	LR	30
31–60	RR	0	121–250	RR	0
61+	NR[2]	0	251+	NR[2]	0

100 kg/ha = 90 lb/acre

[1] HR, MR, LR, RR and NR denote, respectively, high, medium, low, rare and no probabilities of profitable crop response to applied nutrient. Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

[2] No expected agronomic response from additional application of nutrients. Ratings of "NR" may result in reduced yield or affect nutrient balance in crops. For example, additional phosphorus application to a soil >60 ppm phosphorus could induce a zinc deficiency on soils low in zinc and might also increase the risk of phosphorus movement to surface water, while additional potash application to a field already >250 ppm K soil test could induce magnesium deficiency on soils low in magnesium.

Variety Selection

There are no sunflower variety trials conducted in Ontario. Variety testing is conducted through the National Sunflower Association of Canada at (www.canadasunflower.com).

Sunflowers can be classified as either oil or confectionery. Oil-type sunflowers have black hulls and can be conventional hybrids, dwarf hybrids, mid-oleic or open pollinated varieties. Dwarf hybrids mature 6–13 days earlier than conventional hybrids. Open pollinated sunflower (Sunola) varieties are shorter and require less heat to mature than normal sunflowers, but they do not have good disease resistance.

Non-oil-type sunflowers have striped hulls and are grown for the human food market. Only the largest of the confection sunflowers are used for human consumption, but these varieties have little tolerance for bird or insect damage.

Hybrids have many advantages over open-pollinated varieties. Hybrids have approximately 20% greater yield, better disease resistance (especially downy mildew, rust and verticillium wilt), a high degree of self-compatibility, which reduces the need for bees to pollinate, and more uniform height and moisture content at harvest.

Sunflowers are tall, broad-leafed, usually single-stemmed plants, with one head per plant. The stem is hairy and becomes fibrous as the plant matures. Plants are heliotropic, which means that the heads face east by morning and west by evening, following the day's sun. They have a deep taproot system, which allows them access to deep water and nutrient supply that is generally unavailable for many other annual crops. As a result, sunflowers can handle dry soil conditions better than most crops.

Planting

Sunflowers are usually planted in early May, similar to corn, and usually bloom in late July. They require approximately 100–120 days to mature. Seedlings are relatively tolerant to frost up to the four-leaf stage. A delay in planting beyond May 15 will increase the risk of frost damage prior to maturity in the fall. When delays in planting are unavoidable, use early-season hybrids/varieties.

Optimum planting depth is 3–5 cm (1¼–2 in.) and not more than 8 cm (3¼ in.), in moist soil. Shallow planting is suited to cold, wet, fine-textured soil. Sunflowers are prone to lodging in heavier soils or where there is heavy rain and wind.

The ideal row width is 60–90 cm (24–36 in.). Use a corn planter with appropriate seed adjustments or a grain drill with some of the runs plugged. Grain drills typically give poorer emergence. The recommended seeding rate is 40,000–60,000 plants/ha (16,000–24,000 plants/acre). Confection sunflowers should not be seeded at a rate greater than 18,000 plants/acre, to help encourage large seed size. Plant 25% more seed than the desired plant population. Narrow row spacing (18–25 cm or 7–10 in.) and solid stands increase the risk of white mould. Less lodging occurs if rows are planted east to west, as sunflower heads face to the east and cause plants to bend toward the east.

Rotation

Do not plant sunflowers in the same field more than once every 4–5 years, due to disease build-up. Canola, dry edible beans, soybeans and buckwheat are all hosts of white mould (*Sclerotinia*). Monitor rotations with these crops closely or avoid them altogether.

Volunteer sunflowers can also be a problem in some crop rotations. Sunflowers are sensitive to atrazine and other herbicide carryover, such as from some of the sulphonylurea (ALS) herbicides.

Fertility Management

The recommended amount of nitrogen for sunflowers is 90 kg/ha (80 lb/acre). The most efficient use of nitrogen is when most of the nitrogen fertilizer is applied as a side-dress before the plants are 30 cm (12 in.) tall. Test your soil to determine the phosphorous and potash requirements (see *Soil Testing*, on page 155, and Table 7–3, *Phosphate and Potash Recommendations for Sunflowers Based on OMAFRA-Accredited Soil Tests*, opposite page.)

Harvest and Storage

Harvest

Typical sunflower yields in Ontario range from 1,500–2,000 kg/ha (1,300–1,800 lb/acre). Plants are ready for harvesting when the back of the heads turn yellow, and bracts around the head are brown, hard and dry. Seeds at this stage have approximately 50% moisture. Harvest is normally in September to mid-October.

In Ontario, if a crop is late maturing, drying will be facilitated by a killing frost. Use of a desiccant is therefore typically not required. However, early frost may reduce yield and oil content. To avoid this, harvest at a higher percentage moisture and dry seeds to reduce shatter loss and exposure to birds. Minimize the period between maturity and harvest to prevent bird damage and head rot.

Sunflowers are harvested with a combine equipped with a small grain head. Most combines are adapted with long seed-gathering pans extending in front of the cutter bar to collect and salvage shattered seed. The reel is typically removed or raised for sunflower harvest. To prevent seed damage, use the slowest cylinder speeds with the largest openings. Reduce air flow to prevent seeds from being blown through the back.

Storage

After harvest, clean seed to remove trash. For proper storage, seed must contain 9.5% moisture or less. Seed at a higher moisture content should be dried immediately after harvest. Sunflowers dry easily in conventional grain dryers. Confection types may wrinkle or be scorched. Allow to cool before storing.

Caution

Dry at a low temperature, because fine hairs and fibres from the seed coat could ignite when put through the drying fan.

In general, bins will hold 70% as much tonnage of sunflower as corn. They can be stored for short periods at up to 12% moistures. Higher moisture or warm seeds may result in spoilage.

Weed Control

Sunflower seedlings suffer from weed competition. If weeds are not controlled early in the season, crop performance is reduced. As sunflowers mature, they become more able to compete with weeds.

The crop can be harrowed before seedling emergence to remove emerging weeds before they become established. A light spring-tooth harrowing can be done when sunflower seedlings are between the four- and six-leaf stage to remove late-emerging weeds. Harrowing is best done under hot, dry conditions to reduce crop damage. Inter-row cultivation is also recommended.

For herbicide recommendations, see OMAFRA Publication 75, *Guide to Weed Control*.

Insects

Insects are typically not a problem in sunflowers.

Individual descriptions of insects, pests and diseases, scouting and management strategies can be found in Chapter 13, *Insects and Pests of Field Crops*, and Chapter 14, *Diseases of Field Crops*.

Recommended treatments to control insects, pests and diseases can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

Soil Management

8. Soil Management

Soil management is a key component of the crop production system. The best crop production practices applied to a field will not consistently produce a good crop if there has been a history of poor soil management. This chapter will highlight some important points about the soil resource and discuss how to assess the health of the soil. It will conclude with options to address soil problems with management practices that will help maintain or improve soil quality.

The Soil Resource

Soil Formation

The properties of Ontario's soils are related closely to landforms that were created by glacial ice, meltwaters, glacial lakes and wind. Glaciers moved across all of Ontario grinding rock into fine particles, and mixed and moved existing soil. As the glaciers retreated, they dropped soil materials from within the ice itself. The meltwater deposited gravel and sands as mixed layers. Flat beds of sand, silt and clay were deposited by lakes that formed from the ponding of melt waters. The soils were further distributed as strong winds moved across these landscapes. The soils of today were developed on these deposits.

Examples of the landforms include shallow-over-bedrock, muck or peat, till plain, end moraine, sand plain and clay plain. Additional information and photo examples of the landforms can be found in *Best Management Practices: Soil Management*, Order No. BMP06E. See also the Soil Management page on the OMAFRA website at www.ontario.ca/crops.

Soil Variability

The soils of Ontario vary greatly in their make-up due to the scraping and mixing action of glacier movement. As the glaciers melted, wind, water and time contributed to further differences in soil development. Some soils are very shallow to bedrock, others have more than 100 m (328 ft) of overburden. The depth of topsoil varies as conditions for soil formation varied. Soils vary from region to region, from farm to farm and within fields. Observe a soil excavation to see the variation in the depth of soil horizons (shown in Figure 8–1, *Variability in Soil Horizons*, this page). This natural variation often occurs over very short distances.

Growers have been aware of this soil variability for years and have tried to improve areas that were less productive.

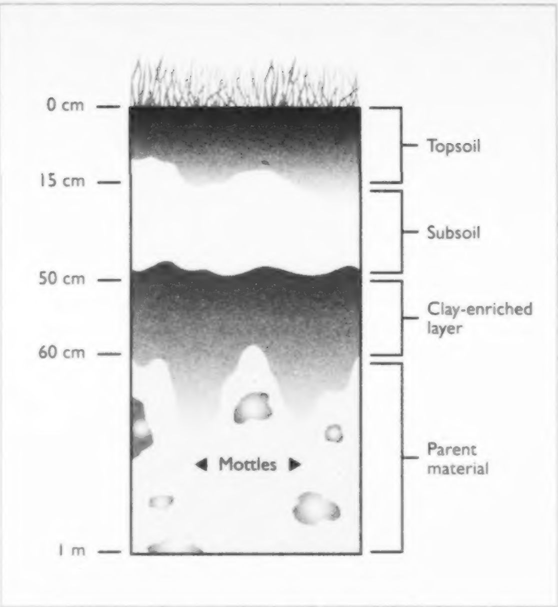


Figure 8–1. Variability in Soil Horizons

Yield monitors have allowed us to see how much that variability can affect yields. In some fields of corn, there can be an over-6.3 t/ha (100 bu/acre) difference between high- and low-yielding areas. Soybeans can have a 2.7 t/ha (40 bu/acre) spread and wheat a spread of up to 5.4 t/ha (80 bu/acre).

Soils can vary in:
- mineral composition, texture, fertility, pH
- soil organic matter: amount and type
- structure, aeration, drainage, density, water-holding capacity
- thickness of horizons, topographic position
- age: degree of weathering, erosion, deposition
- depth to:
  - bedrock
  - water table
  - textural or structural changes

Intensive crop production has contributed to the variation in topsoil depth. Soil erosion by wind, water and tillage has reduced the amount of topsoil in parts of many fields. That topsoil, in some cases, is deposited in other areas of the field, increasing topsoil depth there, while in some fields, the topsoil has been lost totally from areas. Other examples of management that can intensify variability include liming, removal of fence

Table 8–1. Soil Organic Matter Pools

Property	Active Soil Organic Matter (living)	Moderately Stable (dead)	Very Stable (very dead)
Activity	• living or recently deceased • living part includes bacteria, fungi, algae, plant roots, insects, earthworms, etc., which help with the breakdown of residues and manures • supplies nutrients as well as glues for aggregate formation • recently dead includes dead organisms, recently added manures, old plant roots and crop residues • supplies food for organisms	• recently decomposed organic material	• sometimes called humus • virtually untouchable, intimate part of the soil • holds on to some nutrients for slow release • can lessen drainage or compaction problems • can improve water retention in sandy soils
Persistence	• influenced by year-to-year management	• influenced over a farmer's lifetime	• existed long before the field was farmed and will exist long after the farmer retires
Percentage of soil organic matter	10%–15%	40%–45%	40%–45%

rows, compost/manure piles and uneven manure application patterns.

What Is Good Quality Soil?

Soil quality is the measure of a soil's health and its ability to resist erosion, compaction and other stresses, while maintaining economic productivity. Many factors are assessed to determine a soil's health. A healthy soil will:

- have good soil structure, resist crusting and have minimal compaction
- have an abundance of earthworms
- have a fresh, earthy odour
- readily decompose residue
- have good drainage, water movement and water-holding capacity
- encourage seedling emergence and root growth
- produce uniform crop growth and colour
- have nutrient levels, pH and organic matter in the optimal range
- have suffered little wind, water or tillage erosion, and will be resistant to it

Most of the characteristics of a healthy soil have a direct or indirect link to soil organic matter.

Organic Matter

Soil organic matter is a very small component of the soil but it plays a crucial role. Building and maintaining good levels of soil organic matter results in:

- higher-yielding, healthier crops
- crops more tolerant to doughty conditions and other stresses, such as insects and diseases
- a reduced need for commercial fertilizer and lime

Soil organic matter exists in three pools in the soil. See Table 8–1, *Soil Organic Matter Pools*, this page.

Importance of Organic Matter (OM)

Crucial to many aspects of the soil and crop development and with no single role taking precedence, organic matter:

- directly or indirectly influences the availability of nutrients obtained from the soil, playing an important role in many nutrient cycles
- improves the cation exchange capacity (CEC) of a soil by helping the soil hold on to positively charged ions such as calcium, potassium and magnesium making them available to the crop. This is most important in loams and sands, where there is little clay to provide the negative charge to hold the cations.
- forms complex organic acids during the breakdown of organic materials, which also hold on to nutrients, and helps keep iron, zinc and manganese in the chelated or available form
- can buffer soil pH, slowing rapid changes in pH
- darkens soil colour, helping warm the soil faster in the spring
- helps store carbon – there is four times as much C in the soil as in plants
- stores nitrogen — almost all the nitrogen in soils exists as part of the organic matter. Bacteria and fungi convert the organic format to nitrate and ammonium, which can be used by plants.
- maintains the water cycle by keeping the soil open and porous, so more water can soak into the soil. Infiltration, rather than runoff, replenishes soil moisture during dry conditions and contributes to recharge of groundwater. This in turn increases the amount of water that plants can access from the soil, by increasing both storage capacity and rooting volume, and improves drainage of excess water through the soil.
- aerates the soil, creating greater porosity so air can enter the soil more easily

There is also some evidence that organic matter may help prevent phosphorus from being converted to forms that are unavailable to plants.

Soil Life

A healthy soil is full of life. The organisms living in the soil play an important role in the health of the soil and of plants. Soil life includes bacteria, fungi, algae, protozoa, nematodes, earthworms, insects (ants, beetles, millipedes, etc.), larger animals (moles, rabbits, snakes, etc.) and plant roots.

Soil organisms play an important role:

- in the breakdown of organic residues and their incorporation into the soil. As organic materials are decomposed, nutrients become available to plants, humus is produced and soil aggregates are formed.
- creating channels for water infiltration and better aeration
- in moving surface residues deeper into the soil
- in nitrogen fixation
- in fighting plant pests, such as weeds, insects, nematodes and diseases
- stimulating root growth with substances produced by microorganisms

Soil Structure

The term soil tilth is used to describe a soil that is in a favourable condition for crop growth. Soil with good tilth is porous and allows water to enter easily, instead of running off the surface, which makes it more available to plants and results in less erosion. A porous soil allows roots to exchange oxygen and eliminate carbon dioxide more easily, which aids root growth.

Soils and soil structure are formed through the actions of freeze-thaw cycles, wet-dry cycles, root growth, tillage, and soil animals and microorganisms.

The active organic matter in a soil, the decomposing residues and the soil life play a significant role in soil structure development and maintenance. Soil structure is developed from soil particles held together with clay, humus and the glues released from living and decomposing organisms. Good soil aggregation or structure can only be maintained with a continuous supply of organic materials, roots of living plants and soil organisms. Table 8–2, *Types of Soil Structure*, next page, describes soil structure typically seen in soils.

Soil Compaction

Compaction is defined as increased bulk density and reduction in soil pore space. This occurs when the soil particles are forced closer together by the impact of equipment, animals and raindrops. The use of heavier tractors, combines and implements, particularly with earlier spring tillage, can cause problems under any tillage system.

A soil that is in poor tilth has structure that has deteriorated and aggregates that are not stable. This can be seen as increased compaction, decreased aeration and a reduction in water storage. Heavy equipment travelling across the soil can cause significant soil compaction. This can have a negative impact on the soil biology. The reduction in the number of medium to large pores reduces the volume of soil available for air, water and populations of organisms that require large spaces in which to live. There are three types of soil compaction that can be found in the soil: surface crusting, tillage layer compaction and subsoil compaction. See Table 8–3, *Types of Soil Compaction*, on page 141, for a description of each.

Soils having high organic matter contents, good internal drainage and good structure are less susceptible to compaction. For further information, see the OMAFRA website at www.ontario.ca/crops.

Threat to the Resource

The biggest threats to the soil resource are the loss of soil organic matter, the lack of a thriving and diverse population of organisms, and soil compaction.

As agriculture has become more mechanized and many rotations have become shorter and more intense, the quality of many soils in Ontario has declined over the last 4 to 5 decades. The soil is vulnerable to degradation. Soils that are degraded are usually the result of soil erosion and a decline in organic matter levels. Soils in this state often end up on a downward spiral. Further loss of topsoil due to erosion reduces the nutrient content of the soil. The lost soil carries nutrients with it so the topsoil layer becomes less fertile. Tillage of the soil begins to incorporate less fertile soil from below. As organic matter levels decline, the soil becomes less resistant to erosion. The soil also becomes less resistant to soil compaction. As compaction increases, porosity is reduced and there is less air and less water movement through the soil. More runoff causes more erosion. As organic matter levels decline, the soil has less water-holding capacity. The cycle continues in a downward spiral of soil degradation.

Soil Erosion

Soil erosion is a serious threat to the productivity of the soil. Soil erosion is a naturally occurring process, but farming practices have accelerated the rates of erosion. Erosion in agricultural fields involves the detachment and movement of soil particles within and outside the field. It results in:

- decreased crop yields
- increased cost of production
- degraded topsoil
- increased runoff and reduced water storage

Table 8–2. Types of Soil Structure

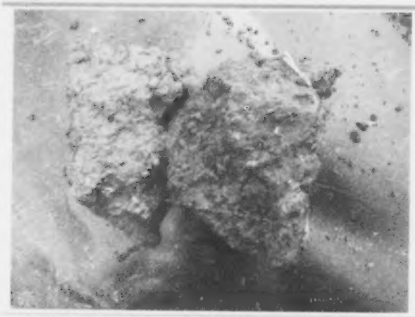
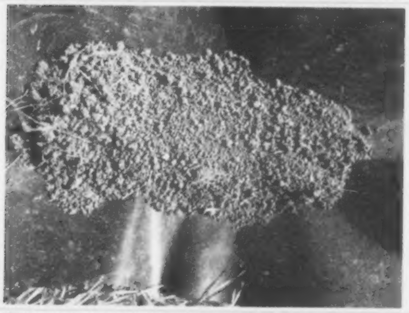
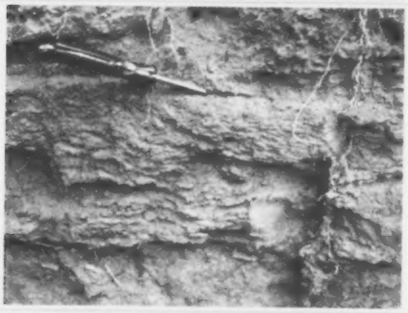
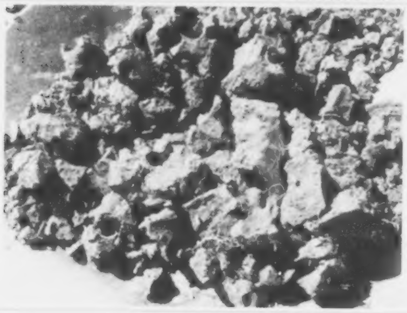
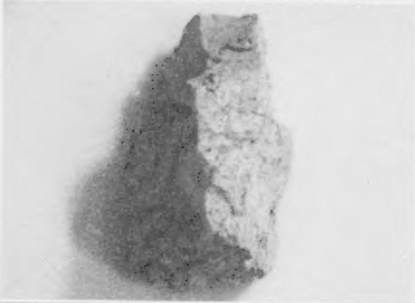
Type		Importance
	**Structureless**	
	Single grain: Soil breaks into individual particles (i.e., low organic matter sands).	• prone to crusting, especially soils with higher clay contents • have little resistance to wind and water erosion
	Massive: Soil breaks into large chunks.	• compact, have very few pores, restrict root growth and water movement
	**Granular**	
	Soil breaks into small aggregates or crumbs.	• usually found in the topsoil layer • ideal topsoil structure • very good water-holding capacity, lots of pore space, good water movement and root growth
	**Platy**	
	Soil particles are arranged in relatively thin horizontal plates.	• often found in the top 8 cm (3 in.) of long-term no-till soils. Coulters cutting through the soil will chop up the plates to form a granular structure with time • can be found in compacted soil layers
	**Blocky**	
	Soil aggregates are cube-like or irregular in shape.	• usually found in the B horizon • promotes good root growth, aeration and drainage
	**Columnar or prismatic**	
	Soil particles are arranged vertically to form prisms or pillar-like aggregates.	• usually found in C horizons with higher clay content • the vertical areas between the aggregates allow root growth and water movement

Table 8–3. Types of Soil Compaction

Cause	Impact
Surface crusting	
• Unprotected soil is dispersed by the action of raindrops and pushed into a thin, dense surface layer.	• Soil is prone to high rates of runoff and water erosion. • The surface becomes sealed, reducing water infiltration. • When dry, a hard crust forms, which can delay or prevent seedling emergence.
Tillage layer compaction	
• Soil is eroded. • Soil has low levels of organic matter. • Heavy field equipment traffic results in soil compaction.	• The layer is very dense, reducing water infiltration and the porosity of the soil. • Root growth may be restricted.
Subsoil compaction	
• Pressure from a disc or plow on the soil below the tillage layer compacts the subsoil. • Pressure from heavy field equipment with poor weight distribution results in compaction.	• Water flow is restricted through the compacted layer. • There will be little or no root growth through the compacted layer.

The three types of soil erosion are water, wind and tillage. Water erosion is the detachment and movement of unprotected soil particles by water. Wind erosion is the detachment and movement of soil particles by air currents or wind. Tillage erosion occurs when tillage equipment lifts soil and moves it forward, gravity pulls it downhill. See the booklets *Best Management Practices: Soil Management,* Order No. BMP06E, and *Best Management Practices: Field Crop Production,* Order No. BMP02E, for more information.

Soil Health Check

The first part of this chapter explained many of the basics of soil and soil management. Topics such as soil variability, soil quality, organic matter, soil life and soil structure were discussed in relation to soil productivity. Knowing the importance of these soil characteristics is good, but how does one determine what impact past and current management practices have on the soil? Table 8–4, *Soil Health Check*, next page, lists a number of soil characteristics and simple assessments that can be done to determine the status of each.

The Soil Health Quiz on the OMAFRA website at www.ontario.ca/crops, in the Soil Management section, provides another format for assessing soil health. The goal of this quiz is to examine the health of soil in specific fields and document the level of health over time. This allows tracking the impact of specific management practices as efforts are made to protect and improve the agricultural productivity.

Assessing the soil quality for each field and taking steps to maintain or improve it will help ensure high productivity. Maintaining soil quality is a long-term process. Some measures are easy and relatively inexpensive to implement, while others require more effort and commitment. The remainder of this chapter will highlight a number of practices to maintain or improve soil quality.

Table 8–4. Soil Health Check

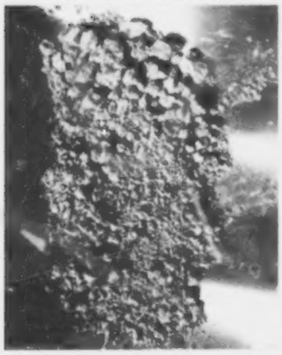
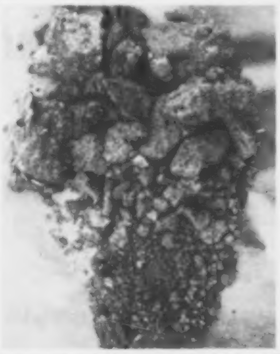
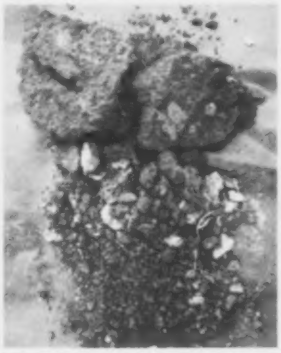
Importance	Assessment
Soil Structure	
• Water moves easily through a well structured soil. • A well-structured soil is very porous (lots of air space). • Roots can penetrate soils with good soil structure more easily. • Poorly structured topsoil will crust, which can reduce crop emergence and water movement into the soil.	• With a shovel, cut a square of soil about the width of the shovel and about 15 cm (6 in.) deep. • Lift it up with the shovel. • Pick the soil up and drop it from waist height. • Compare how the soil breaks apart to the photos below. • Also compare the aggregates to the diagrams and photos in Table 8–2, *Types of Soil Structure*, on page 140.
 **Good condition**  **Moderate condition**	 **Poor condition** **Lift out the square of soil**
Soil Compaction	
• Restricts air and water movement through the soil • Restricts root growth, limiting the plants' ability to take up water and nutrients. • Reduces the size of soil pores. 	• Identify the areas that have potential compaction problems. • Choose a time when the soil is moist. • Using a tile probe or flexible rod, probe the affected area to a depth of 50 cm (20 in.) and compare to a fencerow or unaffected area. • Insert the probe into the ground at a slow, steady speed. • Your arms should be slightly bent, acting as the pressure gauge, measuring the force required to push the tip of the probe through the soil. • Note the depths at which the tip of the probe requires more force to push it through the ground. These areas may be where roots cannot penetrate. • Use a shovel to dig up the plants in the affected area and examine the roots. Compare the roots to healthy plants from an unaffected area. The compacted area will have plants with malformed/restricted roots. Roots may be concentrated in the top 10–20 cm (4–8 in.) of the soil. **Note:** When using a probe to compare compaction in different parts of fields, the areas measured must have similar moisture content for the results to be comparable.
Soil Organic Matter	
• Soil organic matter plays a key role in soil structure, nutrient cycling and water-holding capacity, which can have significant impacts on crop growth.	• Soil samples taken for nutrient analysis to a depth of 15 cm (6 in.) can also be analyzed for organic matter. • Take samples as per the guidelines described in *Soil Sampling*, on page 156, or from areas of concern within a field. • Soil from a fencerow or woodlot can be analyzed for comparison. • See *Organic Matter*, on page 138, and *Adding Organic Material (Residues)*, on page 144, for more information.

Table 8–4. Soil Health Check

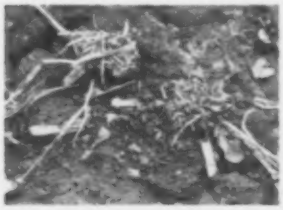
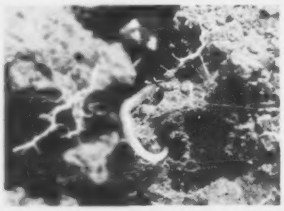
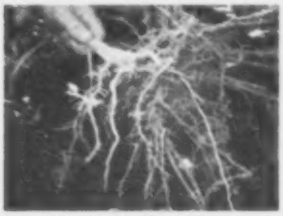
Importance	Assessment
Soil Colour	
• The colour of the surface soil (at the same moisture level) across a field is a visual indicator of soil organic matter levels. • Lighter coloured soil on the side of a knoll in a field can be an indicator of the loss of topsoil due to tillage erosion. • Tilling below the topsoil layer will mix in lower organic matter subsoil, causing those areas to appear lighter.	• Check whether the soil colour across the field is fairly uniform. • Generally, the darker the soil, the higher the organic matter level, if soil moisture levels are equal. • Areas of the field that were old wetlands will usually be darker in colour, as they would have accumulated higher levels of organic matter prior to being drained.
Soil Life	
• Drives organic matter breakdown and nutrient cycling • Plays a role in water movement through the soil • Has an impact on soil structure • A lifeless soil will not be a productive soil  	• Count the number of large earthworm holes (middens, as shown in the photo on the far left) in a square metre: 10 or more per square metre is a good population. • Small earthworm populations can be assessed by digging up a shovelful of soil and breaking it apart to see how many are found. • The smell of a soil can also be an indicator of a healthy soil life population. A sweet, forest smell is good; a swampy smell indicates a less than ideal situation. • See *Soil Life*, on page 139, for more information
Drainage	
Can affect: • Timeliness of field operations • Soil erosion • Root growth • Amount of air in a soil	• Observe the field to see if moisture drains away quickly and the soil is warm and ready for field operations in the spring • Observe the crop to see if excess moisture is reducing yield, except in wet years
Water-Holding Capacity	
• Moisture available for crop growth • Reduces moisture stress during dry periods	• Observe the field to see if the soil stores moisture well. • Observe the crop to see if it suffers during moderate dry spells.
Plant Growth	
• Poor crop growth if not caused by insects, diseases, weeds, the weather or some other circumstance, could indicate a soil problem.	• Observe the crop in the field, especially prior to reproduction; look for differences in growth and in colour of the crop. • The crop should be a dark green colour, and growth should be rapid and relatively uniform. • Yield maps are also a good indicator of differences in crop growth in the field.
Root Growth	
• Poor root growth, if not caused by insects or disease, is likely due to a soil factor. • A plant root explores a large volume of soil for uptake of nutrients and water essential for plant growth. 	• Carefully dig up the plant root. • Generally, there should be a uniform distribution of the roots. • White roots indicate live roots. • Roots will grow down in the soil and on an angle out from the base of the plant, in roughly a straight line. • Roots that take a sudden turn likely encountered a compacted area. • Soil compaction will also restrict roots and result in a shallow or restricted root system.
Nutrient Levels	
• The correct nutrient and pH levels in a soil are essential for good crop growth. • Testing the levels is critical to being able to correct deficiencies.	• See Chapter 9, *Soil Fertility and Nutrient Use*, for information on soil and tissue sampling and how to correct deficiencies.

Table 8–5. Effects of Different Management Practices on Gains and Losses of Organic Matter

Management Practice	Gains/ Increases	Losses/ Decreases
Add materials from off the field (manures, composts, other organic materials).	Yes	No
Manage crop residue better.	Yes	No
Include high residue producing crops in rotation.	Yes	No
Include sod crops (grass/legume forages) in rotation.	Yes	Yes
Grow cover crops.	Yes	Yes
Reduce tillage intensity.	Yes/No[1]	Yes
Use conservation practices to reduce erosion.	Yes/No[1]	Yes

Source: *Building Soils for Better Crops*, (Magdoff) SARE Outreach, www.sare.org

[1] Practice may increase crop yields, resulting in more residue.

Building a Healthy Soil

The key to success in building a healthy soil is effective management of the soil organic matter. As discussed earlier, the organic matter is made up of three parts: active, moderately stable and very stable. The active portion is the part that management can have the most influence on. The organic matter pool continually experiences gains and losses. If the addition of organic material to the soil exceeds the losses, organic matter levels increase; if the losses exceed the gains, organic matter levels will decrease. Table 8–5, *Effects of Different Management Practices on Gains and Losses of Organic Matter*, this page, lists a number of practices and their effect on soil organic matter.

It is important to keep in mind that soil and its management are part of the overall crop production system. Soil is also a central part of the agricultural ecosystem. Changes made in the crop production system over the years have far-reaching effects on all other systems. When taking steps to improve soil quality, think about the changes being made and how they may affect other components of the crop production system.

Adding Organic Material (Residues)

The addition of organic residues is the only sure way to increase soil organic matter levels. Soils that are well aerated, such as sands, break down residues quickly, making it more difficult to build soil organic matter (SOM) levels. Soils with higher clay contents break down residues more slowly, requiring less organic residues to maintain or increase the SOM level.

Table 8–6. Soil Organic Matter Percentage Levels for Different Soil Textures

Soil Texture	Targets	To achieve maximum aggregate stability
Sands and sandy loam	4	3
Loam and silt loam	4–5	4
Clay loam	4–5	7
Clay	4–6	9

Source: Ontario Environmental Farm Plan.

Providing a variety of residue types, such as manure, crop residues, composts, cover crops, biosolids, etc, will support a diverse group of soil life. Determining the right organic matter level for a soil depends on the soil texture and the aggregate stability target. Table 8–6, *Soil Organic Matter Percentage Levels for Different Soil Textures*, this page, shows organic matter targets for various soil textures. The targets indicate soil organic matter percentages to aim for to improve soil productivity. The levels for maximum aggregate stability were derived from research (*Health of Our Soils Report*, AAFC Ottawa) to determine what levels of SOM would give aggregates the most resistance to the erosive forces of water.

Manure

Livestock manure is an excellent source of organic matter for the soil. Applying manure to the soil will provide other benefits, such as a greater diversity and activity of organisms and better soil structure. See Table 8–7, *Effects of 11 Years of Manure Additions on Organic Matter Levels*, opposite page.

Consider the following when using manure as an organic matter source:

- Manure will add organic matter but also adds nutrients. Use the information in Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page 164, to help avoid over-application of nutrients that could lead to loss into the environment.
- The organic matter content of a manure will vary, depending on the type. Generally, more solids will be added to the soil with solid manure than with liquid manure. Solid manure from cattle (ruminants) will contain more forage parts and bedding than liquid manure. See Table 9–8 on page 164, for a listing of typical manure types and their dry matter levels.
- The application rate will also determine the amount of organic matter added to the soil.
- Solid manures usually contain more lignin (forage and bedding), which will have a longer-term effect on organic matter than poultry manure without bedding.
- Apply manure without compacting the soil.

Table 8–7. Effects of 11 Years of Manure Additions on Organic Matter Levels

	Application Rate (tons/acre/year)			
	None	**10 Tons**	**20 Tons**	**30 Tons**
Organic Matter (%)	4.3	4.8	5.2	5.5

Source: *Building Soils for Better Crops*, (Magdoff) SARE Outreach, www.sare.org

Note: The original organic matter level was 5.2%. The study was conducted on continuous corn silage on a clay soil adding dairy manure. The manure application also improved soil aggregation and the amount of pore space.

The nutrient content of manure is discussed in *Manure Management*, on page 163.

Compost

Applying compost to the soil is another way of adding organic matter. Compost will supply relatively low amounts of readily available nutrients but will release nutrients over time. The composting process partially decomposes organic matter, so the organic matter added to the soil is made up of more resistant compounds than in fresh manure. It should not be the only source of organic matter as soils benefit from fresh residues as well. Fresh residues will likely stimulate more production of the sticky material that holds aggregates together than compost will. Similar to manure, it is important to minimize compaction at application and to avoid excessive nutrient additions.

Composting of manure and other materials will:

- help stabilize nutrients
- reduce the amount to spread (volume can be reduced by 30%–60%)
- produce a better-smelling final product

Other Organic Materials

Sewage Biosolids

Sewage biosolids, like manure, are another source of organic matter and nutrients for the farm. As a regulated material, sewage biosolids are monitored to address environmental quality, food safety and human health issues. Sewage biosolids are available for application on agricultural land in many parts of the province. The application rate for a field is based on the soil test results for the field and crop nutrient requirements. The amount of organic matter applied will depend on the rate and type of biosolid.

When applying sewage biosolids, similar to any land operation, ensure the soil is fit, to avoid soil compaction. Work with the applicator to ensure the timing fits with your crop production system.

Visit the OMAFRA website at www.ontario.ca/crops to learn more about biosolids.

Other Agricultural and Non-Agricultural Source Materials

There are a variety of other organic materials that can be applied to soil to add organic matter. Knowing the dry matter content and nutrient content of the material will help calculate application rates and provide an indication of how much organic matter is being added. It is also important to know the carbon-to-nitrogen ratio of the material to assess any potential impacts on nitrogen availability. When calculating the rate of application, consider the physical amount applied and the implications for the rest of the cropping system.

Applying Organic Materials to the Land

The application of organic materials to the land is done to increase organic matter levels and also to add nutrients to the soil. To achieve the maximum benefit and protect the environment, consider how they are applied. See *Considerations When Land-Applying Organic Materials*, below, for a list of some points to consider.

Considerations When Land-Applying Organic Materials

Do I have to incorporate the material?

- Incorporate materials with an odour immediately or as soon as possible.
- Incorporate materials containing ammonium nitrogen as soon as possible to reduce nitrogen losses.
- A certificate of approval or regulation may require incorporation.
- Incorporate nutrient-rich materials on sloping land or flood plains to prevent loss.
- Leave materials that don't meet the above criteria on the soil surface to help protect the soil. Earthworms and other soil life will help break down and incorporate the material.

How much tillage/incorporation is needed?

- Incorporating organic materials with excessive tillage will expose the soil to erosion and reduce or eliminate the benefits of the organic matter addition.
- Depending on the material, a minimal amount of tillage will be sufficient to incorporate most materials. Incorporating some of the material and leaving the rest on the surface is generally best.
- Full inversion mouldboard plowing will leave a layer of material at plow depth that will not readily decompose and may affect water movement through the soil.

Table 8–8. Matching Cover Crop Choices to Function

Cover Crop Function	Best Choices for Cover Crops
Nitrogen production	Legumes – red clover, peas, vetch
Nitrogen scavenging	Fall uptake – oilseed radish and other brassicas, oat Winter/spring uptake – rye, winter wheat
Weed suppression	Fast growing/shading plants – oilseed radish and other brassicas, winter rye, buckwheat
Soil structure building	Grasses – oat, barley, rye, wheat, triticale, ryegrass or fibrous root systems such as red clover
Compaction reduction	Strong tap roots that grow over time – alfalfa, sweet clover
Biomass return to soil	Fall seeded – oat, oilseed radish Summer-seeded – millets, sorghum, sudangrass, sorghum sudan
Erosion protection, i.e., wind, water	Winter rye, winter wheat, ryegrass (well-established), spring cereals seeded early
Emergency forage	Fall – oat, barley, wheat, rye, forage brassicas Summer – millets, sorghum, sudangrass, sorghum sudan
Nematode suppression	Cutlass mustard, sudans/sorghums (Sordan 79, Trudan 8.) pearl millet (CFPM 101), marigold (Crackerjack, Creole), oilseed radish (Adagio, Colonel) **Not all cover crops have the ability to suppress nematode populations; some will even act as hosts. Cover crop activity is variety- and nematode-specific. To get the most activity, cover crops should be weed free and may require specific handling.**

Cover Crops

Growing cover crops is a common soil management practice for many Ontario farmers. There are a lot of good reasons to grow cover crops but it is often hard to put a dollar value on the return from growing them. Cover crops are an important part of a system of soil maintenance — particularly important on the lighter soils with lower organic-matter or on fields with short rotations and little return of crop residue or manure. It is important to know the goal when planting a cover crop and to select the best one for that job. Table 8–8, *Matching Cover Crop Choices to Function*, this page, looks at the various reasons for including cover crops in a rotation and the potential cover crops that best meet those goals.

Choosing a Cover Crop

There are often several cover crop options for any one goal or function. Consider specific farm needs and management style to select the best cover crop for a farming system. Table 8–9, *Choosing a Cover Crop*, opposite page, gives examples of the questions that should be posed when considering a particular cover crop.

Characteristics of Cover Crops

Information on the most commonly used cover crops is provided in Table 8–10, *Characteristics of Cover Crops Grown in Ontario*, on page 148. More information about specific grass and legume cover crops can also be found in Chapter 3, *Forages*.

Grass Crops

Grasses have fine, fibrous root systems that are well suited to holding soil in place and improving soil structure. Suitable grass species for cover crops are fast growing and relatively easy to kill, either chemically, mechanically or by winter weather. Grasses do not fix any nitrogen out of the atmosphere but can accumulate large quantities from the soil.

Grasses are often referred to as either bunch grass or a spreading grass. Bunch grasses generally do not have rhizomes or stolons, just a simple root system supporting the plant. The species with rhizomes or stolons have the ability to send up new shoots from nodes on these structures, allowing the grass to spread and form a sod.

Spring Cereals

Spring cereals are well suited for late-summer and early-fall plantings. Under good growing conditions, spring cereals will produce the greatest amount of crop biomass, making them valuable for feed or ground cover. Once well established, spring cereals are relatively tolerant of frost; do not attempt to establish them late in the fall, as the growth will be disappointing.

Winter Cereals

Winter cereals are highly versatile cover crops. They can be planted in summer and will tiller and thicken due to their need for vernalization or a cold treatment before reproduction, or they can be planted in fall for soil cover. Winter cereals will generally over-winter well, providing winter and spring erosion protection. These grasses can

Table 8–9. Choosing a Cover Crop

Consideration	Comment
Growth habits	• What kind of growth habit is needed? • When is the growth required — lots of vigorous growth in late fall or rapid growth in early spring? • Is deep rooting important?
Overwintering	• Does the cover crop need to survive overwinter? • Would it suit the cropping schedule and soil type if the cover crop winter-killed and dried out by spring ?
Control options	• Will the cover crop become a weed concern? • How is it controlled? • What options are there for control?
Sensitivity to herbicides	• How sensitive is the cover crop to herbicide residues from other crops in the rotation?
Seed cost and availability	• What is the seed cost and is the seed available in your area?
Establishment	• What is the best way to plant the seed? • Is different equipment required? • How easy is it to establish? • Will it create a solid cover? • Good establishment is critical to the success of the cover crop.
Nutrient management	• Is it a nitrogen producer or does the cover crop require nitrogen to grow well? • What is the nitrogen cycle and timing of nitrogen release? • Does it scavenge well for nitrogen?
Pest management	• What crop family is the cover crop in? • Is it related to other crops in the rotation? • Are there pest concerns?

be used to create spring wind barriers, residue mulch or killed early to minimize residue cover at planting.

Warm-Season Grasses

Warm-season grasses such as sorghum and millet are best suited for planting into the warmer soils of late June, July and early August. They are very sensitive to frost. Root growth is extensive and the top growth lush. Be prepared to mow these grasses to keep stalks tender and prevent heading out. Do not mow closer than 15 cm (6 in.) to ensure regrowth. Some nitrogen may have to be applied to achieve optimal growth.

Legume Broadleaf Crops

Legume cover crops can fix nitrogen from the air, supplying nitrogen to the succeeding crop. Legumes will take up residual soil nitrogen or nitrogen from manure applications. They are approximately 80% as effective as non-legumes in nitrogen uptake from soil. Legumes also protect the soil from erosion and add organic matter. The amount of nitrogen fixed varies between species, although generally, more top growth equals more nitrogen fixed. Some legume species such as alfalfa and sweet clover have aggressive tap roots that can break up subsoil compaction, but this requires more than one year's growth.

Non-Legume Broadleaf Crops

These broadleaf crops cannot fix nitrogen out of the air but may absorb large quantities from the soil. Most of these crops are not winter-hardy, so additional control measures are not normally required. They should not be allowed to go to seed, as the volunteer seed can become a significant weed problem.

New and Emerging Cover Crops

Every year new crops are tried as cover crops. Often these species are from different parts of the globe and may not be well adapted to Ontario growing conditions. For more information on new and well-known cover crop species, see the OMAFRA website at www.ontario.ca/crops or the Midwest Cover Crop Council at www.mccc.msu.edu/.

Crop Rotation

Crop rotation is an integral part of the crop production system. The greatest benefit to a good crop rotation is increased yields. A well-planned crop rotation will help with insect and disease control and aid in maintaining or improving soil structure and organic matter levels. Using a variety of crops can reduce weed pressures, spread the workload, protect against soil erosion and reduce risk. Legume crops in the rotation have become more valuable with the increased cost of nitrogen. Research and experience have proven that a good crop rotation will provide more consistent yields, build soil structure and increase profit potential.

Table 8–10. Characteristics of Cover Crops Grown in Ontario

Species	Seeding Rate kg/ha	Normal Seeding Time	Minimum Germination Temperature °C	Nitrogen Fixed or Scavenged (F or S)[1]	Over-Wintering Characteristics	Building Soil Structure	Weed Suppression	Grazing Potential	Quick Growth	Root Type
Grasses										
Spring cereals	100–125	Mid-Aug–Sept	9	S	Killed by heavy frost	Good	Good	Very good	Very fast	Fibrous
Winter wheat	100–130	Sept–Oct	3	S	Over-winters very well	Good	Good	Very good	Fast	Fibrous
Winter rye	100–125	Sept–Oct	1	S	Over-winters very well	Very good	Very good	Very good	Very fast	Fibrous
Sorghum sudan	50	June–Aug	18	S	Killed by frost	Good	Good /fair	Very good	Very fast	Coarse fibrous
Pearl millet	4	June–Aug	18	S	Killed by frost	Good	Good/fair	Good	Fast	Coarse fibrous
Ryegrass	12–18	April–May or Aug–early Sept	4.5	S	Annual, Italian partially survive; Perennial over-winters	Very good	Fair/poor	Good	Slow to establish	Fibrous
Broadleaves – Legumes										
Hairy vetch	20–30	Aug	15.6	F/S	Over-winters	Good	Fair/poor	C[2]	Slow to establish	Tap with secondary fibrous
Red clover	8–10	March–April	5	F/S	Over-winters	Good	Fair	C[2]	Slow to establish	Weak tap/ fibrous
Sweet clover	8–10	March–April	5.5	F/S	Over-winters	Good	Fair	C[2]	Slow to establish	Strong tap
Soybeans	40–50	Aug	8	F/S	Killed by frost	Poor	Good/fair	C[2]	Fast	Tap
Field peas	40–100	Aug	5	F/S	Killed by heavy frost	Poor	Good/fair	C[2]	Fast	Weak tap/ fibrous
Broadleaves – Non-Legume										
Buckwheat	50–60	June through Aug	10	S	Killed by first frost	Poor	Very good	Poor	Fast	Weak tap/ fibrous
Oilseed radish	10–14	Mid-Aug–early Sept	7	S	Killed by heavy frost	Fair	Very good	Good	Fast	Moderate tap
Other brassicas, i.e., forage radish	Varies with species	Mid-Aug–early Sept	5–7	S	Species dependent, many killed by heavy frost	Fair	Very good	Good	Fast	Moderate tap

100 kg/ha = 90 lb/acre

[1] Oilseed radish, buckwheat and the grasses do not fix nitrogen from the air but are scavengers of nitrogen from soil and manure applications.

[2] Clover legumes make good feed or grazing, however feeding pure legumes can cause bloat.

The basic rule of crop rotation is that a crop should never follow itself. Continuous cropping of any crop will result in the build-up of diseases and insects specific to that crop, and cause a reduction in crop yields. The more often the same crop has been grown in the field in the past, the greater this impact will be. For example, the practice of growing two or more years of soybeans is becoming increasingly common. Perhaps the greatest impact of back-to-back years of soybeans has been the accelerated spread of soybean cyst nematode (SCN). For more information and potential yield reductions, see *Soybean Cyst Nematode*, on page 235. The increased number of years of soybeans in the rotation is also increasing the susceptibility of Ontario's soils to erosion.

Table 8–11. Corn Yield Response to Rotation

	Corn Grain Yield[2]	
	Loam (1990–95)	Clay Loam (1990–93)
Rotation[1]	t/ha (bu/acre)	
Continuous corn	8.84 (141)	6.59 (105)
Soybean-corn	9.78 (156)	7.40 (118)
Soybean-wheat-corn	9.47 (151)	7.90 (126)
Soybean-wheat (RC)[3]-corn	10.23 (163)	8.47 (135)
Soybean-wheat (RC)-RC[3]-corn	10.35 (165)	8.28 (132)

Source: Vyn, University of Guelph

[1] On a Toledo loam near Chatham, Ontario, and on a Brookston clay loam near Maidstone, Ontario.

[2] All corn treatments were fertilized with 179 kg/ha (160 lb/acre) of N.

[3] Red clover plowdown was underseeded into wheat. "Wheat (RC)-RC" indicates that underseeded red clover was not plowed under but harvested for seed the following year and then fall plowed.

In fact, the structure of soils in corn-soybean rotations can actually be poorer than that of soils that are in continuous corn production. For example, a recent study found that erosion following an intense June rainstorm in first-year corn following 2 years of soybeans was twice as high as following corn, wheat underseeded with red clover or alfalfa. Relatively poor soil structure after 2 years of soybeans not only increased erosion susceptibility but also reduced soil porosity, which resulted in less rainwater infiltration. Reduced rainwater infiltration increases the likelihood of erosion, yield-reducing water ponding and/or soil moisture deficits; all of these effects can reduce crop productivity, particularly in years with weather-related stress.

The greatest benefit from crop rotation comes when crops grown in sequence are in totally different families. The two families are grasses (monocots) and broadleaves (dicots). The grasses include forages grasses, cereals and corn. Soybeans, white beans, alfalfa and canola are examples of broadleaf crops. Table 8–11, *Corn Yield Response to Rotation*, this page, provides an example of the type of response to crop rotation that is possible.

The fibrous root systems of cereal and forage crops (including red clover) are excellent for building soil structure. Studies have shown that the benefits of including wheat, and especially wheat plus red clover, may persist beyond just the following year. Underseeding red clover into wheat resulted in yield increases every year for 3 consecutive years compared to when red clover was not included in 4-year rotation systems.

In choosing which crop to grow, consider the economics of the entire rotation instead of a single crop in isolation. See Publication 60, *Field Crop Budgets*, for cost estimates, or visit the OMAFRA website at www.ontario.ca/agbusiness.

Also, be aware of any potential insect or disease problems that could affect crops later in the rotation. Cover crops in the rotation may also have an impact on diseases and pests, either positive or negative (see *Cover Crops*, on page 146, for potential impacts of various cover crops). Table 8–12, *Management Considerations for Various Crop Rotations*, next page, displays various crop rotations that are recommended, cautioned against or not recommended, depending on their impact on the crop production system. It is not a comprehensive listing of crop problems but does highlight the main issues to be aware of. More information is provided in each crop chapter.

Reducing Losses of Organic Matter

Reducing Soil Erosion

Soil erosion occurs to some extent on most agricultural soils. Factors affecting erosion include soil texture, intensity of rainfall, slope steepness, length of slope and management factors such as crop rotation and tillage practices. A number of the measures already mentioned in this chapter can help control or reduce the amount of soil lost from a field. Minimizing the amount of tillage used can reduce tillage erosion. Minimum till, no-till, improved drainage and crop rotation, including cover crops, can go a long way to reducing wind and water erosion. Table 8–13, *Soil Management Practices to Reduce Soil Erosion*, on page 151, shows benefits of various practices to water, wind and tillage erosion.

In some situations, these measures are not enough, especially where water flow is concentrated, and other soil conservation practices become necessary. A number of structures can be used to control a concentrated flow that is causing a gully or rill in a field. These structures will require less maintenance if combined with minimum till or no-till. Improved tillage and cropping practices can also reduce the size of the structure required. Strip cropping is another option for protecting the soil from water erosion. This practice involves planting alternating strips of row crops with a cereal or forage. Combining conservation tillage with strip cropping will increase the width of the strips required.

See the booklets *Best Management Practices: Soil Management*, Order No. BMP06E, *Best Management Practices: Field Crop Production*, Order No. BMP02E, and the OMAFRA website at www.ontario.ca/crops, for more information.

Table 8–12. Management Considerations for Various Crop Rotations

	Previous Crop						
Crop	**Corn**	**Soybeans**	**Forages**	**Spring Cereals**	**Winter Cereals**	**Dry Edible Beans**	**Canola**
Corn	• yield depression • corn rootworm • European corn borer • slugs may cause damage in no-till	• European chafer (on light-textured soils)	• wireworms following grassy sod	**• heavy residue in no-till may delay soil drying and warming**	**• heavy residue in no-till may delay soil drying and warming**		**• may adversely affect crop growth**
Soybeans	• slugs may cause damage in no-till	**• yield depression** **• soybean cyst nematode** **• root diseases** **• degrades soil**	**• weed escapes may be difficult to control** **• slugs may reduce stand**	• slugs and delayed planting could affect no-till	• slugs and delayed planting could affect no-till • spider mites following clover cover crop	**• white mould** **• degrades soil** **• soybean cyst nematode (maybe)**	• white mould • can adversely affect crop growth
Forages	• heavy residue may interfere with seed placement in no-till	• check for herbicide carry-over	• forage diseases could increase autotoxicity of alfalfa				
Spring cereals			• wireworms (following grassy sod)	**• leaf diseases** **• yield depression**	**• leaf diseases** **• yield depression**		• may be slight reduction in growth
Winter cereals	• increased risk of fusarium head blight	• European chafer (on light-textured soils)	• weed escapes • reduced growth no-till into quackgrass	• take-all • leaf diseases	• take-all • leaf diseases • yield depression		**• may be slight reduction in growth**
Dry edible beans		**• white mould** **• root rots** **• soybean cyst nematode (maybe)**	• weed escapes • slugs in no-till	• slugs may cause damage in no-till	• slugs may cause damage in no-till	• yield depression • root rots • white mould • soil structure	• white mould • may adversely affect crop growth
Canola	**• slugs may cause damage in no-till** **• harvest is too late for winter canola planting** **• check for herbicide carryover**	• white mould • check for herbicide carryover	• slugs may reduce stand		• slugs may cause damage in no-till	**• white mould**	• white mould • blackleg • root rots • yield depression • check herbicide carryover

Legend: Recommended **Caution** Not recommended

Table 8–13. Soil Management Practices to Reduce Soil Erosion

Practice	Effect	Other Benefits	Water	Wind	Tillage
Reduced tillage	• leaves residue on the soil surface, effectively controlling erosion • loosens less soil • prevents soil from being moved down slope by tillage implements	• improved water infiltration • reduced organic matter loss • improved soil structure	x	x	x
Adding organic materials	• protects the soil from erosion by leaving material on the soil surface • promotes soil tilth (better water infiltration equals less runoff) and larger and more stable aggregates (less erosion), due to higher organic matter levels in soil	• added nutrients • increase of organic matter levels • improved soil structure • improved soil life	x	x	
Crop rotation	• protects the soil by keeping the soil surface covered year round (grass and legume forage crops) • helps hold soil in place with the extensive root systems (perennial crops) • helps protect the soil from fall through to harvest (fall-planted annual crops such as winter wheat)	• improved soil structure and less soil compaction because of root systems • improved water infiltration • higher yields • reduction in insect and disease build-up	x	x	
Cover crops	• protect the soil by covering it when it might otherwise be left bare • help improve soil structure to resist erosion and improve infiltration, less runoff due to added organic matter • soil held in place by the roots	• increase organic matter levels • help hold onto nutrients from recently applied manure • provide forage • weed and nematode supression	x	x	

Stream and Ditch Protection

Ditch and stream banks are often a significant source of sediment in water. Unprotected banks will continue to erode, cutting into valuable farmland. Increasing pressure to protect groundwater and surface water underlines the need to protect this resource. A number of measures can protect stream and ditch banks as well the water flowing in them. High stream flows, cattle and machinery can subject banks to erosion. Concentrated flows entering a watercourse can cause rill or gully erosion. Buffer strips, tile outlet protection or header tile, drop pipes and rock chutes can help stabilize streambanks and ditches.

Restrict livestock from all watercourses; many fencing options are available. Bridges, culverts or low-level crossings are some of the options available to move livestock and machinery safely.

See the Best Management Practices booklets listed at the end of this chapter.

Windbreaks and Shelterbelts

Often additional protection from the wind is necessary when there is not enough residue to hold soil in place. Windbreaks and shelterbelts can provide that protection by slowing down wind speeds near the ground. Windbreaks also create a micro-climate, raising soil and air temperatures adjacent to the trees, reducing drying winds and accumulating more snow. These effects also provide crop yield increases. See Figure 8–2, *Windbreaks Provide Protection to Crops*, next page.

Fragile Land Retirement

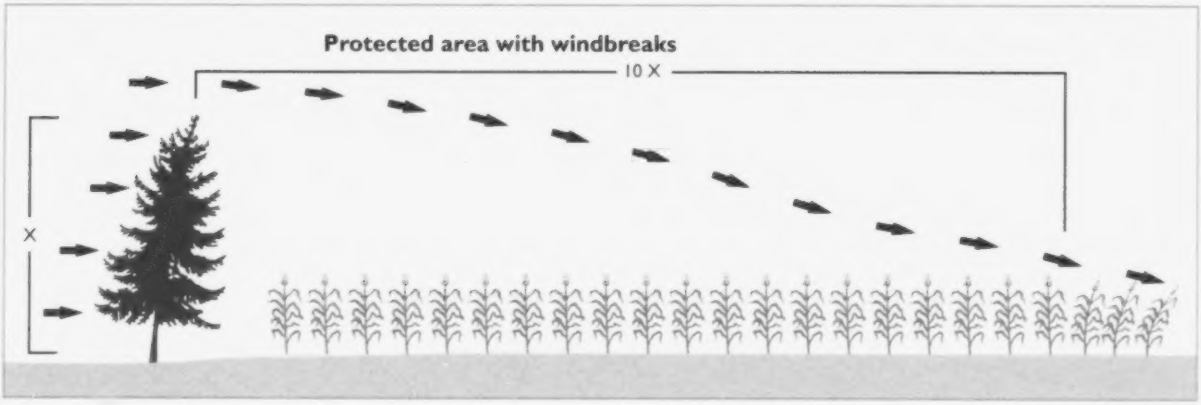
Occasionally, the erosion cannot be controlled on a field or part of a field. The erosion may be too extreme, or the field has some other limitation, making it unprofitable or unsustainable to farm. Fragile land could include areas along creeks, lakes and wetlands that may be subject to flooding or other land that is subject to severe erosion. This land should be retired from production to forest or pastureland.

Preventing Compaction

As discussed earlier, compaction occurs easily with the use of heavy farm equipment, especially when soils are wet.

A number of management options can help prevent soil compaction:

- Keep off the field when the soil is wet, particularly with heavy equipment. The carrying capacity of dry soil is much greater than that of moist soil.



Protected area with windbreaks

Figure 8–2. Windbreaks Provide Protection to Crops

Crop yields can increase 10%–20% if the field is protected by a tree windbreak.

- Ensure tillage operations are performed when the soil is at proper moisture conditions at tillage depth.
- Install tile drainage in fields with variable or poor drainage.
- Use longer crop rotations that include forages/cereals.
- Leave forage crops in for more than 1 year.
- Alternate tillage depth so that tillage pans are not created.
- Minimize the amount of traffic on a field.
- Use radials, large tires or tracks that create a long narrow footprint to restrict compaction.
- Reduce the tire pressure to reduce the force on the surface of the soil. This will only be effective with radial tires and with large enough tires to carry the equipment at the reduced pressures. Check with the manufacturer that the tires are rated to operate at low pressures.
- Avoid high axle loading, which will cause compaction in the subsoil, even with low tire pressure. Keep equipment weight and loads as low as practical (below 4.5 tonnes/axle or 5 tons/axle). As often as possible, limit traffic with heavy equipment to laneways rather than tracking the entire field.

Subsoiling or Deep Tillage

Subsoiling is often used to try to loosen compacted areas of fields where heavy loads have passed. Generally, subsoiling does not provide any long-term benefits. Always check for the presence of compaction using a tile probe or soil pit and check the moisture at depth before subsoiling. See *Soil Health Check*, on page 141, for a description of how to detect soil compaction. Deep tillage where the soil is not compacted will not provide any benefit and may damage soil structure or drainage tile below the normal depth of tillage.

Change soil management, harvesting and manure application practices to avoid further problems. These changes include using lighter loads and staying off the soil when it is wet below the surface.

Reducing Tillage

Soil is tilled for a number of reasons. Those include weed control, soil levelling, burying of crop residues, incorporation of fertilizer and manure and seedbed preparation. The advent of herbicides greatly reduced the need for tillage to control weeds (except in the organic system) and the development of equipment to plant into crop residues means that crops can be planted successfully with little or no tillage. Generally, performing primary tillage operations in the spring will leave the soil less prone to erosion than tillage in the fall. Try to use the least amount of tillage necessary to achieve the goal.

See the tillage sections of each specific crop in this publication for additional information.

Moldboard Plow

From a soil quality perspective, the moldboard plow is the least desirable tillage method because it leaves little residue on the soil surface, requires multiple passes of secondary tillage and is energy and labour intensive. Plowing and secondary tillage pulverize aggregates, making the soil more prone to crusting and erosion. If moldboard plowing is used, set the plow to stand the furrows on edge and try to leave some residue on the surface. Also minimize the number of secondary tillage passes to reduce the breakdown of soil aggregates.

Chisel Plow

The chisel plow will leave more residue on the surface than the moldboard plow, depending on how it is set up, amount of crop residue and the amount of secondary tillage used. Chisel plowing with twisted shovel teeth will leave the soil ridged, which is good for soil erosion control but can require extra tillage passes in the spring and lead to uneven soil moisture in the seedbed. Many of these problems can be overcome by:

- using sweep teeth on all or part of the chisel plow
- adding a levelling bar or harrows to the rear of the chisel plow
- timely secondary tillage in the spring

The chisel plow can also be an effective tool for incorporating manure.

Disc

The disc, like the chisel plow, will leave more residue on the soil surface than the moldboard plow. Using this tool when the soil is too wet can cause soil compaction. Too many passes will break down soil aggregates and increase the loss of soil organic matter and risk of crusting. A good planter set up to handle some residue and a rougher seedbed can help reduce the number of secondary tillage passes in any tillage system.

No-Till, Zone Till and Strip Till

No-till systems provide the greatest opportunity to leave protective crop residues on the soil surface. They also have the greatest potential for reducing tillage costs, offset somewhat by the need to control weeds in nearly all cases with a preplant "burndown" herbicide application. Numerous options exist both in the original design and in the modifications available for row crop planters or seed drills to be considered "no-till" capable.

In Ontario, the term "no-till" generally describes planting the crop into a field with no previous tillage passes, with just the seed opener or with one coulter in front of the seed opener. **Planting into the soil the spring after fields were tilled in the fall and left ready to plant is not no-till.**

Zone tillage systems usually have two or three coulters in front of the seed and fertilizer openers and may also include trash wheels.

Strip tillage utilizes a toolbar with coulters in front, followed by a shank and a couple of disks at the back. It may be used in the fall, spring or both to prepare a seedbed. The shank typically operates at a 10–15 cm (4–6 in.) depth.

The success of no-till systems is often dependent on a range of factors other than the equipment design. Two of these — soil drainage and crop rotation — have a significant influence on the performance of all no-till systems. Reduced tillage systems present the greatest challenge for planting corn. Tillage systems are described in more detail in Chapter 1, *Corn*.

Environmental Considerations

Good soil management has significant benefits for the soil. It can also provide other environmental benefits by helping to protect water quality. Many of the activities on the farm can have an impact on the environment. The Environmental Farm Plan (EFP) has helped farmers understand the environmental risk of these activities since 1993. The EFP is a self-assessment tool that examines 23 different areas of the farm. All levels of government, conservation authorities and a few organizations have provided at least some financial incentives for land owners to make improvements. If not already implemented, consider completing an EFP. Check with governments and other organizations for funding opportunities to make environmental improvements on the farm. The EFP program is administered by the Ontario Soil and Crop Improvement Association.

Water Quality

Water is a valuable resource. A clean and abundant supply of water is critical to the success of a farm business and the health of the family. Others, including fish and wildlife, also share the water. It is a privilege to have an ample supply of clean water and a responsibility to make sure the water leaving the farm is abundant and clean for the next user.

Farm operations impact water quality in many ways. Soil erosion, manure, septic system effluent, milkhouse wastes, pesticides and fuels can affect surface water quality. Nutrients, manure, pesticides and fuels moving down through the soil can affect groundwater quality.

The greatest water quality challenges affecting producers involve bacteria (from manure), nitrates and sediment. Pesticide contamination is much less of a problem.

Air

There are three main issues related to air on the farm — odour, dust and greenhouse gases. The OMAFRA website and the Best Management Practices booklet series offer a number of options to address these issues.

Best Management Practices booklets published by OMAFRA/Agriculture and Agri-Food Canada/ Ontario Federation of Agriculture contain more information on water quality problems and solutions as well as fish and wildlife management, irrigation, nutrient management, agroforestry and greenhouse gases.

Best Management Practices

Farming is a business with many risks: the weather, finances, and market uncertainties. Today, we also realize that certain farming practices may create environmental risks that affect water quality.

Producers experience some of the resulting problems themselves such as lower crop yields, soil losses and water pollution. But rural and urban neighbours may also be affected. Not all problems are severe, and not all farms have problems. But for those producers who are affected, practical solutions exist. The books and other products of the Best Management Practices Program cover workable solutions for soil, water and habitat problems.

Order No.	Title
	An Introduction to Best Management Practices
	A First Look
BMP15E	*Buffer Strips*
BMP21E	*Establishing Tree Cover*
BMP01E	*Farm Forestry and Habitat Management*
BMP02E	*Field Crop Production*
BMP10E	*Fish and Wildlife Habitat Management*
BMP17E	*Greenhouse Gas Reduction in Livestock Production Systems*
	Horticultural Crops
BMP09E	*Integrated Pest Management*
BMP08E	*Irrigation Management*
BMP20E	*Managing Crop Nutrients*
BMP16E	*Manure Management*
BMP11E	*No-Till: Making It Work*
BMP14E	*Nutrient Management Planning*
BMP13E	*Pesticide Storage, Handling, and Application*
BMP06E	*Soil Management*
BMP19E	*Streamside Grazing*
BMP07E	*Water Management*
BMP12E	*Water Wells*
BMP18E	*Woodlot Management*

Soil Fertility &
Nutrient Use

9. Soil Fertility and Nutrient Use

Principles for Optimum Management of Nutrients

In 2006, Ontario used about 686,000 tonnes (756,000 tons) of fertilizers. Figure 9–1, *Trends in Retail Fertilizer Sales*, this page, shows the trends in fertilizer use over the past five decades. High yields can be produced efficiently only when fertilizer use is related to the fertility level of the soil and to other additions of nutrients from manure, crop residues and other organic sources. At one extreme, on very low fertility soils, it is occasionally profitable to add as much or more nitrogen, phosphorus or potassium in the fertilizer as a crop removes. At the other extreme, on high fertility soils or following heavy application of manures, adding fertilizer may not be profitable and may occasionally reduce yields.

Proper management of nutrients balances the requirements of the crop being grown, the nutrients already available in the soil and the proper timing and placement of nutrient additions for the greatest crop response and the least environmental impact.

For more detailed information regarding management of fertilizer and other nutrients, see OMAFRA Publication 611, *Soil Fertility Handbook*.

Soil Testing

Soil testing is the most accurate tool available to determine nutrient requirements for a crop. It is actually made up of three discrete steps:

1. Collecting a representative sample from the field
2. Analyzing the sample using OMAFRA-accredited soil tests
3. Relating the results of the soil analysis to nutrient requirements for optimum crop yields

Other Methods of Assessing Nutrient Needs

- Plant analysis is the main tool used for tree fruits and can provide additional information to support the soil test for field and vegetable crops.
- Nutrient deficiency symptoms on crop leaves are helpful in evaluating nutrient deficiencies. In some cases, however, they have serious drawbacks, particularly with potassium and phosphorus, because serious yield losses occur before symptoms are visible.

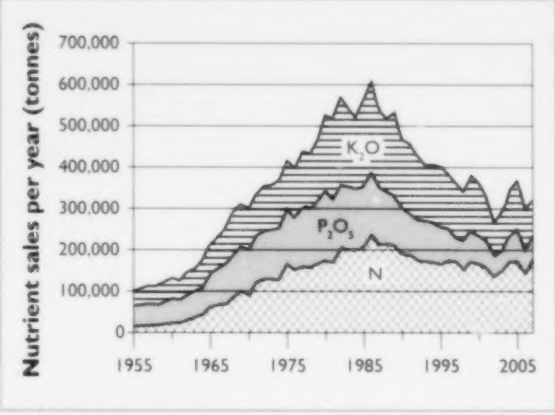


Figure 9–1. Trends in Retail Fertilizer Sales

- It is occasionally suggested that a grower apply the amounts of nutrients removed by the crop. This has some application for nitrogen since the suggested rate approximates what the plant removes for crops such as corn. It has little relevance for other nutrients in Ontario. Some clay and clay loam soils have sufficient potassium to last many years, and application of potassium each year on those soils is uneconomical and ignores one of the few advantages that clay soils have over coarser-textured soils.

The OMAFRA-accredited soil testing program is the main guide, along with help from plant analysis and nutrient deficiency symptoms, in determining the fertilizer requirements for a specific crop on a specific field.

The OMAFRA-Accredited Soil-Testing Program

The OMAFRA-accredited soil-testing program provides assurance of appropriate analyses to support recommendations for nitrogen, phosphate, potash and magnesium fertilizer, along with recommendations for the amount and type of lime to apply. The analytical methods used were chosen to provide accurate results on the range of soils found in Ontario. Table 9–1, *OMAFRA-Accredited Soil Tests*, next page, lists the tests provided on an accredited soil test in Ontario.

Nitrate nitrogen can be measured from a separate, deeper sample. See Chapter 1, *Corn*, for further information.

9. Soil Fertility and Nutrient Use

Principles for Optimum Management of Nutrients

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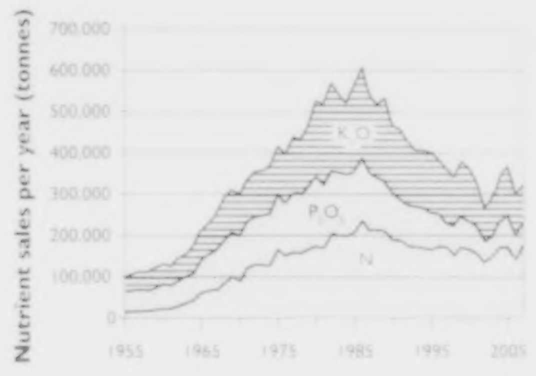

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Table 9–1. OMAFRA-Accredited Soil Tests

Materials Analyzed	What Is Analyzed[1]
Soils for field crops, commercial turf, etc.	Plant-available phosphorus (sodium bicarbonate extractable); potassium, magnesium (ammonium acetate extractable), manganese and zinc (index of soil pH and extractable element); pH; lime requirement (SMP buffer pH)

[1] Soil organic matter can be useful for herbicide recommendations but is not an accredited test.

Units on soil test reports

Soil test results for phosphorus, potassium and magnesium are reported in units of milligrams per litre of soil (mg/L), which is approximately equal to parts per million (ppm). Plant-available phosphorus is measured with a sodium bicarbonate extract (also known as the Olsen extract). Plant-available potassium and magnesium are measured with an ammonium acetate extract. Manganese and zinc are reported as indexes that account for both the amount of nutrient extracted from the soil and the soil pH. Soil pH has a huge impact on the amount of these nutrients that is available to plants.

These analyses have been found to be the most accurate estimates of plant-available nutrients for soils in Ontario.

The OMAFRA-recommended fertilizer rates are provided in this publication. They are designed to produce the highest economic yields when accompanied by good or above-average management. Research shows that higher-than-recommended rates of fertilizer will occasionally produce higher yields, but that these increases in yield are likely to be small and not profitable. Some fertilizer is recommended at soil test levels slightly above those where crop response is profitable. This is done to maintain high soil nutrient levels and to allow for some error in sampling the field. For high-value crops such as tomatoes, the maximum profit aimed for will require essentially the same amount of fertilizer as maximum crop value (maximum yield with high quality). For low-value crops, there may on occasion be a slight yield response to rates of fertilizer above those recommended for maximum profit. However, trials on farm fields with corn have shown no yield response to rates of fertilizer above those recommended by an accredited soil test. For further assistance in interpreting soil test reports, contact a Certified Crop Advisor or call the OMAFRA Agricultural Information Contact Centre (1-877-424-1300).

See Appendix C, *Accredited Soil-Testing Laboratories in Ontario*, on page 260, for a list of accredited labs in Ontario.

Soil Tests From Other Laboratories

Each year, a number of growers ask OMAFRA staff to interpret results from laboratories that are not accredited. Provided the laboratory uses the identical test used by the OMAFRA-accredited service and expresses its test results in the same units, the OMAFRA fertilizer requirements for phosphate and potash can be determined, but there is no assurance how accurate the analyses are.

Only OMAFRA-accredited soil tests can be relied on to provide accurate fertilizer recommendations. To be accredited, a laboratory must use OMAFRA-approved testing procedures, must demonstrate acceptable analytical precision and accuracy, and must provide the OMAFRA fertilizer recommendations.

A number of laboratories provide soil tests such as cation exchange capacity, aluminum, boron and copper. These tests are not accredited by OMAFRA because they have not been found to contribute to better fertilizer recommendations. Research has shown that on Ontario soils, use of cation exchange capacity to adjust potash recommendations can lead to less reliable recommendations than are currently provided.

Soil Sampling

Sample soils with a sampling tube or a shovel. Sample each field or uniform section of a field separately. Take at least 20 soil cores, 15 cm (6 in.) deep, from any field or area sampled up to 5 ha (12.5 acre) in size. For fields larger than 5 ha (12.5 acre), proportionately more cores should be taken. See Figure 10–1, *Scouting Patterns*, on page 178, for appropriate sampling patterns for soil sampling. The more cores taken, the more likely the sample will provide a reliable measure of the fertility in the field. One sample should not represent more than 10 ha (25 acres).

Collect the soil in a clean plastic pail, break up the lumps and mix the soil well. Place a subsample into a soil sample box and forward it for testing. Traverse the sampled area in a zigzag pattern to provide a uniform distribution of sampling sites. Where parts of a field differ in appearance (of soil or crop) or in previous fertilization (manuring or liming), sample separately. This applies even if they are too small to fertilize separately. Avoid sampling recent fertilizer bands, dead furrows, areas adjacent to gravel roads or where lime, manure, compost or crop residues have been piled.

When to Sample

Sample each field once every 2 or 3 years. Potash levels can change quickly where large amounts of nutrients are removed from sandy soils (i.e., alfalfa hay, corn silage, potatoes or tomatoes). Under these conditions, take samples each year.

To allow time for mailing and analysis, take soil samples from fields that will be fertilized for spring-seeding crops in the fall. With the rush of harvest and the frequency of poor weather in late fall, summer may be a more convenient time for some growers to soil sample.

Sample Boxes and Information Sheets

Soil sample boxes, information sheets and information on the cost of various tests are available from any of the accredited labs, or from many fertilizer and farm supply outlets.

Management practices such as manure application or legume sod plowed down can affect a soil test recommendation and the crop to be fertilized. This information is essential for a reliable fertilizer recommendation and should be recorded on the field information sheet that must accompany the soil sample sent in for analysis.

For more information on sampling and analysis, see the OMAFRA Factsheet, *Soil Sampling and Analysis for Managing Crop Nutrients,* Order No. 06-031, or visit the OMAFRA website at www.ontario.ca/crops.

Micronutrient Tests

OMAFRA-accredited tests are available for manganese and zinc. In the case of zinc on corn, the soil test is best used in conjunction with visual deficiency symptoms. With manganese, plant analysis, visual symptoms and the soil test are all useful. OMAFRA-accredited tests are not available for boron, copper, iron or molybdenum. Current tests for these nutrients have not provided good estimates of the availability of these nutrients to plants. Plant analysis is generally a better indicator of deficiencies of these nutrients.

Contamination

Great care is required to prevent contamination of soil samples with micronutrients, particularly zinc. Do not use galvanized (zinc-plated) soil sampling tubes to take soil samples for micronutrient tests. Do not use metal containers to collect and mix samples. Clean plastic containers in good condition should be satisfactory. Soil samples that have contacted galvanized surfaces are unsatisfactory for zinc soil tests. Be careful to keep dust around buildings, etc., out of the samples.

Soil Sampling

Micronutrient deficiencies frequently occur in small patches in fields. In these cases, soil or plant analysis taken from the entire field is unlikely to identify the problem. Collect separate samples of problem and adjacent good areas to allow for diagnostic comparison.

Plant Analysis

Plant analysis measures the nutrient content of plant tissue. Comparing the results against the "normal" and "critical" values for the crop can indicate whether nutrient supply is adequate for optimum growth.

Plant analysis is the basis of fertilizer recommendations for tree fruits and grapes and is a useful supplement to soil testing for evaluation of the fertility status of other crops. It is independent of soil testing and can provide a valuable "second opinion," especially for phosphorus, potassium, magnesium and manganese. It is less reliable for nitrogen and zinc. For boron and copper there is not a reliable soil test, so plant analysis and visual symptoms are the methods used for diagnosing deficiencies.

Plant analysis has limitations. Interpreting the results is often difficult since plant-tissue analysis does not usually indicate the cause of a deficiency or the amount of fertilizer required to correct it. Plant analysis is most useful if combined with visual inspection of the crop and soil conditions, knowledge of past management in the field and a current soil test to provide information about soil nutrient levels and soil pH.

There is no formal accreditation process for plant tissue analysis. However, accredited labs that perform plant analysis are monitored and provide quality analysis and interpretation of plant tissue samples.

Sampling

The time of sampling has a major effect on the results, since nutrient levels vary considerably with the age of the plant. Results are difficult to interpret if samples are taken at times other than those recommended. Nevertheless, sample plants suspected of being nutrient deficient as soon as a problem appears. Samples are best taken from a problem area rather than from the entire field, and it is often helpful to sample an adjacent area of healthy plants at the same time, for comparison.

Take samples for plant analysis from at least 20 plants distributed throughout the area chosen for sampling. Each sample should consist of at least 100 gm (3.5 oz) of fresh material. Sample problem areas separately. Avoid contaminating plant tissue samples with soil. Even a small amount of soil will cause the results to be invalid, especially for micronutrients.

Sample Preparation

Deliver samples of fresh plant material directly to the laboratory. If they are not delivered immediately, dry them to prevent spoilage. Samples may be dried in an oven at 65°C or less, or dried in the sun provided precautions are taken to prevent contamination from dust or soil. Avoid contact of samples with galvanized (zinc coated) metal, brass or copper.

Fertilizer Recommendations

Soil Acidity and Liming

The pH scale ranging from 0 to 14 is used to indicate acidity and alkalinity. A pH value of 7.0 is neutral. Values below 7.0 are acidic, and those above 7.0 are alkaline. Most field crops grow well in a soil pH range from 6.0 to 8.0.

To correct soil acidity, broadcast ground limestone and work it into the soil at rates determined by a soil test. Table 9–2, *Soil pH at Which Lime Is Recommended for Ontario Crops*, this page, shows the pH values below which liming is recommended and the target soil pH to which soils should be limed for different crops. In Ontario, most crops grow quite well at pH values higher than the target pH to which liming is recommended.

The Buffer pH

The soil pH measures the amount of acidity in the soil solution and indicates whether liming is necessary for crop production. It does not measure the amount of reserve acidity held on the clay and organic matter particles in the soil, which will dictate how much lime is needed. Different amounts of reserve acidity will mean that two soils at the same pH value will need different amounts of lime to raise the pH to the desired level. The reserve acidity is measured in a separate test: the buffer pH. The greater the amount of reserve acidity, the lower the buffer pH and the more lime is required to raise the pH. For soils needing lime, Table 9–3, *Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH*, opposite page, may be used to determine the amount of lime required to reach different "target" soil pH values required.

Table 9–2. Soil pH at Which Lime Is Recommended for Ontario Crops

Crops	Soil pH Below Which Lime Is Recommended	Target Soil pH[1]
Coarse and medium-textured mineral soils (sand, sandy loams, loams and silt loams)		
Perennial legumes, oat, barley, wheat, triticale, beans, peas, canola, flax, tomatoes, raspberries, strawberries, all other crops not listed below	6.1	6.5
Corn, soybeans, rye, grass, hay, pasture, tobacco	5.6	6.0
Potatoes	5.1	5.5
Fine-textured mineral soils (clays and clay loams)		
Alfalfa, cole crops, rutabagas	6.1	6.5
Other perennial legumes, oat, barley, wheat, triticale, soybeans, beans, peas, canola, flax, tomatoes, raspberries, all other crops not listed above or below	5.6	6.0
Corn, rye, grass hay, pasture	5.1	5.5
Organic soils (peats and mucks)		
All field and vegetable crops	5.1	5.5

[1] Where a crop is grown in rotation with other crops requiring a higher pH (for example, corn in rotation with wheat or alfalfa), lime the soil to the higher pH.

Limestone Quality

Calcitic limestone consists largely of calcium carbonate, and dolomitic limestone is a mixture of both calcium and magnesium carbonates. Dolomitic limestone should be used on soils with a magnesium soil test of 100 or less, as it is an excellent and inexpensive source of magnesium for acidic soils. On soils with magnesium tests greater than 100, calcitic or dolomitic limestone may be used.

The two main factors that affect the value of limestone for soil application are the neutralizing value and particle size. Neutralizing value is the amount of acid a given quantity of limestone will neutralize when it is totally dissolved. It is expressed as a percentage of the neutralizing value of pure calcium carbonate. A limestone that will neutralize 90% is said to have a neutralizing value of 90. In general, the higher the calcium and magnesium content of a limestone, the higher the neutralizing value.

Table 9–3. Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH

Ground limestone required – t/ha (ton/acre)
(based on Agricultural Index of 75)

Buffer pH[1]	Target Soil pH			
	7.0	6.5[2]	6.0[3]	5.5[4]
7.0	2 (0.9)	2 (0.9)	1 (0.5)	1 (0.5)
6.9	3 (1.3)	2 (0.9)	1 (0.5)	1 (0.5)
6.8	3 (1.3)	2 (0.9)	1 (0.5)	1 (0.5)
6.7	4 (1.8)	2 (0.9)	2 (0.9)	1 (0.5)
6.6	5 (2.2)	3 (1.3)	2 (0.9)	1(0.5)
6.5	6 (2.7)	3 (1.3)	2(0.9)	1 (0.5)
6.4	7 (3.1)	4 (1.8)	3(1.3)	2 (0.9)
6.3	8 (3.6)	5 (2.2)	3 (1.3)	2 (0.9)
6.2	10 (4.5)	6 (2.7)	4 (1.8)	2 (0.9)
6.1	11 (4.9)	7 (3.1)	5 (2.2)	2 (0.9)
6.0	13 (5.8)	9 (4.0)	6 (2.7)	3 (1.3)
5.9	14 (6.2)	10 (4.5)	7 (3.1)	4 (1.8)
5.8	16 (7.1)	12 (5.4)	8 (3.6)	4 (1.8)
5.7	18 (8.0)	13 (5.8)	9 (4.0)	5 (2.2)
5.6	20 (8.9)	15 (6.7)	11 (4.9)	6 (2.7)
5.5	20 (8.9)	17 (7.6)	12 (5.4)	8 (3.6)
5.4	20 (8.9)	19 (8.5)	14 (6.2)	9 (4.0)
5.3	20 (8.9)	20 (8.9)	15 (6.7)	10 (4.5)
5.2	20 (8.9)	20 (8.9)	17 (7.6)	11 (4.9)
5.1	20 (8.9)	20 (8.9)	19 (8.5)	13 (5.8)
5.0	20 (8.9)	20 (8.9)	20 (8.9)	15 (6.7)
4.9	20 (8.9)	20 (8.9)	20 (8.9)	16 (7.1)
4.8	20 (8.9)	20 (8.9)	20 (8.9)	18 (8.0)
4.7	20 (8.9)	20 (8.9)	20 (8.9)	20 (8.9)
4.6	20 (8.9)	20 (8.9)	20 (8.9)	20 (8.9)

[1] Buffer pH in Ontario is measured using the Shoemaker, MacLean and Pratt (SMP) buffer. Other jurisdictions may use different buffers, which will give similar but not identical results.

[2] Lime if soil pH below 6.1.

[3] Lime if soil pH below 5.6.

[4] Lime if soil pH below 5.1.

The second factor that affects the value of limestone as a neutralizer of acidity is the particle size. Limestone rock has much less surface area to react with acid soil than finely powdered limestone and, hence, it neutralizes acidity much slower — so much slower that it is of little value. The calculation of a fineness rating for ground limestone is illustrated in Table 9–4, *Example Calculation of the Fineness Rating of a Limestone*, this page.

Table 9–4. Example Calculation of the Fineness Rating of a Limestone

Particle Size	% of Sample		Fineness Factor		
Coarser than No.10 sieve[1]	10	x	0	=	0
No.10 to No. 60 sieve[2]	40	x	0.4	=	16
Passing through No. 60 sieve	50	x	1.0	=	50
Fineness Rating				=	66

[1] A #10 Tyler sieve has wires spaced 2.0 mm apart.

[2] A #60 Tyler sieve has wires spaced 0.25 mm apart.

The Agricultural Index

This index has been developed in Ontario as a means of combining the neutralizing value and the fineness rating to compare various limestones that are available.

$$\text{The Agricultural Index} = \frac{\text{neutralizing value} \times \text{fineness rating}}{100}$$

The Agricultural Index can be used to compare the relative value of different limestones for neutralization of soil acidity. Lime with a high Agricultural Index is worth proportionately more than lime with a low index because it may be applied at a lower rate.

For example, if two ground limestones, A and B, have Agricultural Indices of 50 and 80 respectively, the rate of application of limestone A required for a particular soil will be 80/50 x the rate required for limestone B. Limestone A spread on your farm is worth 50/80 x the price of limestone B per tonne.

Recommendations from the OMAFRA soil test service are based on limestone with an Agricultural Index of 75. If the Agricultural Index is known, a rate of application specifically for limestone of that quality can be calculated. This can be done using the following equation:

$$\begin{array}{c}\text{Limestone}\\\text{application rate}\\\text{from soil test}\end{array} \times \frac{75}{\begin{array}{c}\text{Agricultural Index of}\\\text{Limestone}\end{array}} = \begin{array}{c}\text{Rate of}\\\text{Application of}\\\text{Limestone}\end{array}$$

For example, if there is a limestone requirement by soil test of 9 t/ha, and the most suitable source of limestone from a quality and price standpoint has an Agricultural Index of 90, then apply 7.5 t/ha (75/90 x 9).

The Agricultural Index does not provide information about magnesium content. Dolomitic limestone should be used on soils low in magnesium.

Tillage Depth

Lime recommendations presented here should raise the pH of the top 15 cm (6 in.) of a soil to the listed target pH. If the soil is plowed to a lesser or greater depth than 15 cm, proportionately more or less lime is required to reach the same target pH. Where reduced tillage depths are used, reduce rates of application proportionately. More frequent liming will be needed.

Lowering Soil pH

On soils with pH values below 6.5, it is possible to lower the pH (make the soil more acidic) by adding sulphur or ammonium sulphate. This may be desirable for some crops, for example, potatoes for scab control, but usually will not be suitable for rotation crops. Soil pH cannot be adjusted from a low pH to a more moderate pH year to year. If the soil pH is above 6.5, it is not advisable and also usually quite impractical to lower the soil pH because of the very large amounts of sulphur or ammonium sulphate required.

Changes in Crop Management

Fertilizer requirements on the OMAFRA soil test report are specific to selected crop and management. Adjustments in fertilizer requirements may be needed where manure is applied or legumes will be incorporated. Changing the crop from the original soil test recommendation will require a new fertilizer recommendation. This can be obtained by looking up the appropriate table under the specific commodity chapter in this publication.

Nitrogen

Nitrogen fertilizer recommendations for field crops are based on estimated crop requirements. Recommended rates are presented in tables found in the *Fertility Management* section for each crop chapter. Rates are adjusted downward if manure is applied, or if the previous crop contains perennial legumes such as alfalfa.

To protect crop quality and avoid movement of nitrogen into the groundwater, the combined application of fertilizer, manure, biosolids and residuals, and other sources of nitrogen should not supply plant-available nitrogen in excess of the crop's requirement.

Phosphate and Potash

Phosphate and potash recommendations are based on OMAFRA-accredited soil tests. The requirements of these nutrients are presented in the *Fertility Management* section for each crop chapter. Only use these tables with OMAFRA-accredited soil tests. Non-accredited tests may use extractants that pull out different amounts of nutrient so they will not give correct values if used with the published OMAFRA tables.

Where a soil test is not available, a rough estimate of requirements can be obtained from these tables using the following guidelines:

- Where the field has been fertilized regularly for a number of years, or heavily in recent years, use one of the rates of phosphate and potash recommended for the moderately responsive (MR) soil test rating.
- If the field has received little fertilizer in the past, use one of the rates recommended for a highly responsive (HR) soil test rating.

When the soil test response rating for phosphorus is NR, (no profitable response) the soil contains much more plant-available phosphorus than is required by most crops. Application of phosphorus in fertilizer, manure or biosolids may reduce crop yield or quality. For example, phosphate applications may induce zinc deficiency on soils low in zinc and may increase the risk of water pollution.

The risk of surface water contamination by phosphorus may be increased at higher soil test phosphorus levels. Since phosphorus binds tightly to soil particles, the movement of soil off the field through erosion is a major factor in determining the risk of surface water contamination. It is for this reason that the risk of surface water contamination by phosphorus cannot be based solely on a soil test phosphorus level. Wherever soil tests show a very low or no probability of response to added phosphorus, application of any source of phosphorus should be guided by a Phosphorus Index (see the NMAN Software, the Nutrient Management Workbook or the OMAFRA Factsheet, *Determining the Phosphorus Index for a Field*, Order No. 05-067). A Phosphorus Index ranks the relative risk of surface water contamination for applications made to a particular area of land. It will also determine maximum application rates, if manure is applied, and suggested setbacks from watercourses.

Some clay and clay loam soils are naturally high in potassium and do not require any potash fertilizers. Only a soil test can adequately determine potash requirements.

Magnesium

Magnesium is a nutrient that is naturally plentiful in many Ontario soils. Although rare, when magnesium soil tests are below 20, according to an OMAFRA soil test, magnesium application will be required for production of most crops. If the soil pH is below 6.0, the most effective and inexpensive means of supplying magnesium is by application of dolomitic lime. Use dolomitic lime to correct soil pH if the magnesium soil test is below 100. On soils with a higher magnesium test, use either dolomitic or calcitic lime to correct soil pH. If the pH is above 6.0 and the soil test result is 20 or below, supply magnesium by either magnesium sulfate or sulfate of potash magnesia (a mixture of sulfate of potash and magnesium sulfate). Apply 30 kg/ha (27 lb/acre) of actual soluble magnesium. These latter sources of magnesium are usually quite expensive compared to supplying magnesium from dolomitic limestone.

Potassium competes with magnesium for uptake by crops, and potash applications can therefore induce or increase magnesium deficiency. For this reason, it is important to monitor soil potassium levels and carefully control potash fertilizer applications on low magnesium soils.

Crops grown on a number of Ontario soils are low in magnesium to the extent that livestock health is affected, although the crops themselves do not suffer from magnesium deficiency. In these situations, it is usually much more economical to add magnesium to the animal's diet than to add it to the soil. Soil potassium should be closely monitored and potash applications restricted to requirements as measured by soil test.

Calcium

Calcium deficiency has not been a problem in Ontario soils with soil pH adequate for field crop growth. Adequate soil pH is a reliable indicator of adequate calcium in the soil.

Sulphur

Sulphur is generally provided in adequate amounts for crop growth in acid precipitation, livestock manure and organic matter breakdown. There have been reports of sulphur deficiencies from a few fields in Northwestern Ontario, mainly on sandy soils with low organic matter. Where sulphur is required, apply it as either ammonium sulphate or potassium sulphate. Elemental sulphur can be used, but it must be oxidized to the sulphate form before the plants can absorb it. It therefore needs to be applied 12–18 months before a crop requiring sulphur is planted.

Micronutrient Fertilizers

Apply micronutrient elements only on competent advice or where experience has proven their application to be necessary. Generally, make soil applications during soil preparation and foliar applications during the growing season. Include a spreader sticker in micronutrient sprays applied directly to crop foliage.

Table 9–5. Manganese Soil Test Interpretation

Manganese Index[1]	Suggested Treatments
greater than 30	Soil manganese availability is adequate for field-grown crops.
16 to 30	Soil manganese availability is adequate for many crops but is approaching deficiency levels for oat, barley, wheat and soybeans. If deficiency symptoms appear, spray with manganese. Consider a re-check for deficiency using plant analysis.
below 16	Soil manganese availability is believed to be insufficient for oat, barley, wheat and soybeans. Spray with manganese at the 4-leaf stage and again 3 weeks later if required. Manganese deficiency has not been diagnosed on corn in Ontario, even on soils that are very deficient for wheat.

[1] These values are indices of manganese availability based on extractable soil manganese and soil pH.

Do not combine micronutrient elements with insecticide or fungicide sprays unless the manufacturer's directions indicate that this may be done.

Manganese

Preventing and Correcting Manganese Deficiency

The general symptom of manganese deficiency is interveinal chlorosis of leaves, which begins on the younger foliage. Later, the whole plant may be affected. Cereals show manganese deficiency as a general yellowing and stunting, occasionally with grey specks on the leaves. The crops most susceptible to manganese deficiency are soybeans, dry edible beans and cereals.

Manganese is less available at high soil pH, so it is important not to add more lime than is needed to correct soil acidity. For materials and rates to correct a deficiency, consult the individual crop chapters under *Micronutrients*. Interpretation of the manganese soil test is found in Table 9–5, *Manganese Soil Test Interpretation*, this page.

Zinc

Preventing and Correcting Zinc Deficiency

Corn is the main crop that may show zinc deficiency in Ontario. Zinc deficiency has been reported in beans in other areas but it appears to be rare in Ontario. High phosphorus in the soil and/or in the fertilizer can cause or increase the severity of zinc deficiency. **Apply only the recommended amount of phosphorus.** Use of animal manures can prevent or reduce zinc deficiency. Erosion control can prevent deficiency of zinc by maintaining the topsoil.

Table 9–6. Zinc Soil Test Interpretation

Zinc Index[1]	Suggested Treatments
greater than 200	Suspect contamination of the sample or of the field.
25 to 200	Soil zinc availability is adequate for most field-grown crops.
15 to 25	Zinc availability is adequate for most field crops but is bordering on deficiency for corn. If the field sampled is uneven in soil texture, pH or erosion, some areas may respond to zinc applications. Deficiency symptoms at the 4–6-leaf stage are a reliable indication of zinc deficiency (see *Zinc*, previous page).
less than 15	Zinc is likely to be deficient for corn and should be applied in the fertilizer.

[1] These values are indices of zinc availability based on extractable soil zinc and soil pH.

Zinc deficiency can be prevented by application of zinc fertilizer to the soil at a rate of 4 kg/ha (3.6 lb/acre). Broadcasting up to 14 kg/ha (12.5 lb/acre) will correct a deficiency for 3 years, but do not band more than 4 kg/ha (3.6 lb/acre). Foliar sprays can be useful to correct a deficiency after the symptoms have appeared, provided this is done early in the growing season. Interpretation of the zinc soil test is found in Table 9–6, *Zinc Soil Test Interpretation*, this page.

Copper

Copper soil tests are quite unreliable on Ontario soils, but plant analysis is useful. Copper is unlikely to be deficient on mineral soil, except perhaps on very sandy soils. Copper deficiency does occur on organic soils and is best diagnosed by plant analysis. When organic soils are first brought into cultivation, apply copper to the soil at 14 kg/ha (12.5 lb/acre) for each of the first 3 years.

Boron

Boron is required for alfalfa, particularly on sandy or gravelly soils with low water-holding capacity. Deficiencies are more common in Central Ontario than in the rest of the province. Boron deficiency occurs most frequently during dry weather, and the response to boron may be inconsistent. It has not been possible to develop a reliable soil test. Plant analysis is useful as a predictor of boron requirements as are visual symptoms on the plants. For rates of boron to correct a deficiency, see *Micronutrients*, on page 68.

Boron is needed only in very small quantities, and since an overdose is toxic, take extreme care in its use. Boron deficiency has not been diagnosed in cereals, peas or beans in Ontario, and boron applications to these crops or applied to other crops in the year preceding them can be toxic. **Do not band boron.**

Table 9–7. Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down

Type of Crop	For All Crops, Deduct From N Requirement kg/ha	For All Crops, Deduct From N Requirement lb/acre
Less than one-third legume	0	0
One-third to half legume	55	49
Half or more legume	110	100
Perennial legumes seeded and plowed in the same year	45[1]	40[1]
Soybean and field bean residue	0[2]	0[2]

[1] Applies where the legume stand is thick and over 40 cm (16 in.) high.

[2] For all crops other than corn. For adjustments to corn fertilizer requirements, see *Corn Nitrogen Rate Worksheet*, on page 21.

Iron and Molybdenum

Iron and molybdenum have not been found to be deficient in field crops in Ontario.

Changes in Crop or Management

Fertilizer requirements on the OMAFRA soil test report are specific to selected crop and management. Adjustments in fertilizer requirements may be needed if changes are made in manure application or if legumes are going to be incorporated. For fertilizer adjustments, see Table 9–7, *Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down*, this page. Changing the crop from the original soil test recommendation will require a new fertilizer recommendation. This can be obtained by looking up the appropriate table under the specific commodity chapter in this publication.

Adjustments to Fertilizer Recommendations

The general fertilizer recommendations in this book apply to situations where no organic sources of nutrients have been applied to the field. If manure or biosolids are applied to the land, or if legumes are plowed down, reduce the fertilizer rates to adjust for the nutrients applied in the organic form.

Adjustment for Legumes Plowed Down

When sod containing perennial legumes such as alfalfa, birdsfoot trefoil and clover are plowed under, they supply an appreciable amount of nitrogen to the following crop. Table 9–7, *Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down*, opposite page, shows reductions that should be made in nitrogen fertilizer applications to crops following sod containing legumes.

Adjustments for Manure Application

A large number of Ontario farms produce livestock, generating over 33 million tonnes of manure annually. Proper management of the nutrients from manure is essential for optimum economic benefit to the farmer with minimal impacts on the environment.

Estimating Nutrients Available to the Crop From Average Values

The best way of determining the amount of each nutrient from manure is to analyze a sample. Unfortunately, this is not always possible, as in the case of a new barn. In this case, average values will provide an estimate of the nutrients available to the crop.

Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, next page, provides estimates of available nutrients from various types of manure. It is based on the average results from manure analyses at the five accredited labs in Ontario. Nitrogen is reported as available N under various application systems. Phosphate and potash values are reported as nutrients available to replace fertilizer nutrients. These values can be used as the starting point in crediting nutrients from manure application.

The availability of manure N to the crop depends on the proportion of ammonium and organic N in the manure, as well as the timings of application and incorporation. The ammonium nitrogen in manure is chemically the same form of nitrogen as in many mineral fertilizers and is immediately available to the crop. Unfortunately, the ammonium form is also subject to loss by volatilization if not incorporated immediately. The balance of the nitrogen in manure is in the organic form, which becomes available to crops gradually as the organic compounds break down.

More precise estimates of available nutrients can be made by accounting for the actual timing and conditions for manure application, and the lag time before incorporation. The worksheet, *Calculating Available Nutrients from Spring-Applied Manure Using a Manure Analysis*, on page 168, or the NMAN software, can help with this process.

Manure Management

The Value of Manure

The value of manure in crop production is often underestimated. Manure contains all of the nutrients needed by crops but not necessarily in the proportions needed for specific soil and crop conditions. In addition to nitrogen, phosphorus and potash, manure contains many secondary nutrients and micronutrients, as well as organic matter that help build and maintain soil structure.

An Example

A farmer spreads 45,000 L of liquid finisher swine manure per hectare (4,000 gal per acre) in the spring, working the manure into the soil within 24 hours.

Fertilizer	**Equivalent Amt**		**Price/kg**[1]		**Value/ha**
Nitrogen	153 kg/ha	×	1.90	=	$290.70
P_2O_5	66 kg/ha	×	2.50	=	$165.00
K_2O	96 kg/ha	×	1.50	=	$144.00
Total value per hectare				**=**	**$599.70**

The equivalent amount of commercial fertilizer can be calculated using Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, next page, and Table 9–13, *Typical Manure Analysis by Livestock Type*, on page 167. At the sample prices for commercial fertilizer shown in this chart, the approximate value of the manure is $600/ha ($243/acre), assuming that all nutrients are needed by the crop.

[1] Price based on average commercial fertilizer costs in 2008.

Nutrient Management Plans

A nutrient management plan matches the nutrients available from manure, cover crops, commercial fertilizer and the soil to the nutrients required by the crop. Analysis of nutrients contained in the manure, along with soil test results and crop requirements, help determine the manure application rate and additional commercial fertilizer requirements.

A nutrient management plan may restrict the rate of manure or fertilizer applied if that application could create certain risks, as shown below:

Criteria	**Risk**
Nitrogen	nitrate leaching into groundwater
Phosphorus	phosphate movement into surface water
Volume of liquid	direct runoff, carrying ammonia, phosphate and pathogens

Table 9–8. Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources

Type	D.M.	Available N			Available P_2O_5	Available K_2O
		Fall[1]	Spring[2]	Spring inject[3]		
Liquid Materials	%	kg/1000 L (lb/1,000 gal)				
Hog finisher	7.6	3.1 (30.7)	3.8 (38.2)	4.9 (49.4)	2.1 (21)	3.2 (32)
Hog weaners	3.0	1.6 (15.8)	2.0 (19.9)	2.6 (25.7)	1.3 (13)	1.7 (17)
Hog SEW	2.2	1.3 (12.5)	1.5 (14.8)	1.9 (18.9)	0.6 (5.5)	1.4 (14)
Hog dry sows	1.9	1.3 (13.0)	1.8 (18.3)	2.4 (24.1)	0.9 (9.2)	1.2 (12)
Dairy liquid ave	8.4	1.4 (14.4)	1.5 (15.4)	1.9 (19.2)	0.8 (7.7)	2.6 (26)
Dairy 10%–18%	14	2.0 (20.1)	2.0 (19.7)	2.4 (24.2)	1.3 (13)	3.4 (34)
Dairy 6%–10%	8.0	1.5 (14.8)	1.6 (16.2)	2.0 (20.2)	0.7 (6.9)	2.6 (26)
Dairy 2%–6%	4.4	1.0 (9.8)	1.2 (11.6)	1.5 (14.7)	0.5 (5.0)	2.0 (20)
Beef liquid ave	7.9	1.3 (12.7)	1.4 (13.6)	1.7 (16.9)	0.7 (7.3)	2.3 (23)
Beef 10%–18%	15	2.0 (19.7)	1.9 (19.1)	2.3 (23.3)	1.2 (12)	3.6 (36)
Beef 6%–10%	7.8	1.4 (13.5)	1.5 (14.5)	1.8 (18.2)	0.7 (7.2)	2.2 (22)
Beef 2%–6%	3.8	0.9 (8.6)	1.1 (10.6)	1.4 (13.6)	0.5 (4.5)	1.6 (16)
Runoff 0%–2%	0.7	0.2 (2.1)	0.3 (2.7)	0.4 (3.5)	0.1 (1.0)	0.9 (9.2)
Poultry liquid ave	11	4.2 (41.8)	5.0 (49.6)	6.4 (63.5)	14 (28)	16 (32)
Biosolids aerobic	2.0	0.5 (5.0)	0.4 (4.1)	0.4 (4.4)	0.6 (5.5)	0
Biosolids anaerobic	4.4	1.2 (11.8)	1.2 (11.8)	1.4 (13.8)	1.3 (13)	0
Solid Materials		kg/tonne (lb/ton)				
Hog solid average	30	3.1 (6.1)	3.6 (7.2)	4.3 (8.6)	4.3 (8.5)	6.0 (12)
Dairy 18%–30%	21	1.7 (3.4)	2.1 (4.2)	2.4 (4.8)	1.5 (3.0)	5.0 (10)
Dairy 30% +	39	2.0 (3.9)	2.1 (4.1)	2.3 (4.5)	1.6 (3.1)	5.5 (11)
Beef 30% +	38	2.9 (5.7)	2.4 (4.8)	2.7 (5.3)	3.5 (6.9)	8.0 (16)
Beef 18%–30%	24	1.9 (3.8)	1.9 (3.7)	1.2 (4.2)	1.5 (3.0)	5.0 (10)
Horses average	37	1.5 (3.0)	1.4 (2.8)	1.6 (3.1)	1.4 (2.8)	4.7 (9.3)
Sheep average	34	3.2 (6.4)	3.8 (7.5)	4.5 (8.9)	2.6 (5.2)	8.4 (16.7)
Poultry layers	34	8.7 (17.4)	9.3 (18.6)	11.3 (22.5)	8 (16)	8.5 (17)
Poultry pullets	48	12.2 (24.5)	12.7(25.3)	14.5 (28.9)	13 (25)	15 (29)
Poultry broilers	68	10.8 (21.6)	11.3 (22.5)	12.4 (24.7)	13 (25)	17 (33)
Biosolids dewatered	32	11.3 (22.6)	12.3 (25.6)	13.7 (27.3)	12 (24)	1.2 (2.4)

[1] Late fall application or early application with cover crop.
[2] Spring application incorporated within 24 hours.
[3] Injection or immediate incorporation, assumes good coverage.

Availability of Manure Nitrogen to Crops

The amount of nitrogen contained in manure that is available to crops will depend on the characteristics of the manure, the time that it is applied and how soon following application the manure is incorporated into the soil. The relevant manure characteristics are the total N content, the proportion that is in the mineral (ammonium) and organic forms, and the rate of breakdown of the organic material to release mineral N.

Mineral Nitrogen From Manure

Ammonium-N (NH_4-N) is immediately available to the crop, as nitrogen is from mineral fertilizers, but it is also subject to volatile loss to the air. Manure from different farming systems contains varying proportions of organic and ammonium-N. Liquid manure contains a higher proportion of the nitrogen in the ammonium form than solid manure. The proportion of ammonium-N and organic-N can be determined from a manure analysis, or estimated from the values in Table 9–9, *Approximate Ammonium-Nitrogen as a Percentage of Total Nitrogen in Various Manure Types*, opposite page.

Table 9–9. Approximate Ammonium-Nitrogen as a Percentage of Total Nitrogen in Various Manure Types

Type	Ammonium-N[2]
Liquid Manure[1]	
Liquid hog	66%
Liquid dairy	42%
Liquid beef	43%
Liquid poultry	67%
Solid Manure	
Solid hog	26%
Solid dairy	21%
Solid beef (high bedding)	12%
Solid horse	15%
Solid poultry (broilers)	6%
Solid poultry (layers)	46%
Composted cattle	0.6%
Municipal Biosolids	
Aerobic sewage biosolids	1.6%
Anaerobic sewage biosolids	35%
Dewatered sewage biosolids	12%
Lime Stabilized sewage biosolids	trace
Paper Mill biosolids	trace
Spent Mushroom compost	5%

Source: NMAN software.

[1] Ammonium content increases as liquid concentration increases.
[2] Balance of nitrogen is in organic form.

Table 9–10. Estimated Percentage of Ammonium-Nitrogen Lost Due to Weather and Soil Conditions

		Cool (<10°C)		Warm (>25°C)	
Days After Application	**Average**	**Wet**	**Dry**	**Wet**	**Dry**
Spring					
Incorporated within 1 day	25	10	15	25	50
Incorporated within 2 days	30	13	19	31	57
Incorporated within 3 days	35	15	22	38	65
Incorporated within 4 days	40	17	26	44	73
Incorporated within 5 days	45	20	30	50	80
Not incorporated	66	40	50	75	100
Injected (covered)	0	0	0	0	0
Summer/early fall (with or without incorporation)					
Bare soil	66	40	50	75	90
Crop residue	50	30	35	60	70
Standing crop (below the canopy)	35	25	25	40	50
Late fall–applied	25	25	25	N/A	N/A

Adapted from Beauchamp, University of Guelph, 1995.

As soon as the manure is applied to the field, the ammonium-N starts to volatilize into the air. This process continues until the manure is moved into the soil by incorporation or rainfall, or until the ammonium-N in the manure is depleted to the point that it is stable. Manures that are incorporated quickly will provide much more nitrogen to the crop. The rate of ammonium-N loss will depend on the soil moisture and weather conditions at the time of application. Moist soils increase the opportunity for ammonium to be absorbed in the soil water. Warm temperatures increase the rate of ammonium loss to the air. The estimated losses under various conditions are listed in Table 9–10, *Estimated Percentage of Ammonium-N Lost Due to Weather and Soil Conditions,* this page.

The balance of ammonium-N that remains in the soil is available for crop uptake, or for loss to the environment if there is no crop present to take up the nitrogen.

Organic Nitrogen From Manure

Organic nitrogen is not available to the crop until it has been mineralized to the ammonium form by microbial action. The amount of mineralization will vary with the type of manure, as the organic material in some manure is more resistant to breakdown than in others. As a general rule, the organic-N will become available more quickly from manure from animals receiving a concentrate-based diet compared to a forage-based diet. The percentage of available nitrogen available from the organic portion of manure is shown in Table 9–11, *Estimated Percentage of Organic Nitrogen Available in Year of Application,* next page. The speed of mineralization increases with warm temperatures and adequate moisture, which promote microbial growth, and will almost stop when soil temperatures approach freezing. Nitrogen from solid manure applied just before planting may not be available in time to meet the requirements of the crop.

Ammonium-N, whether applied directly or from the mineralization of organic-N, is further converted to nitrate-N by microbial action in the soil. Unlike ammonium-N, which will adhere to soil particles, the nitrate ion can move freely with soil water.

Loss of nitrate-nitrogen (NO_3-N) through leaching or denitrification will occur if manure (especially liquid manure that is high in NH_4-N) is applied in the summer or early fall. The amount of loss will depend on how much nitrate-N is produced, which in turn depends on the time required for ammonium-N and organic-N to be converted to nitrate-N. Late-summer applications of manure have a greater chance of nitrate-N losses than manure applied just before freeze-up or in the spring.

Table 9–11. Estimated Percentage of Organic Nitrogen Available in Year of Application

Manure Type	%
Liquid – poultry	0.3
Liquid – all other	0.2
Liquid & solid – biosolids	0.3
Solid – poultry/mink/fox	0.3
Solid – swine	0.25
Solid – < 50% DM	0.15
Solid – > 50 % DM*	0.05

Table 9–12. Estimate of Available Nitrogen From Late Summer- and Fall-Applied Manure

	Available Nitrogen[1,2]				
	Incorporated (<24 hours)			Not Incorporated[3]	
Application Time	Late Summer	Early Fall	Late Fall	Early Fall	Late Fall
Urea (commercial N)	0.1	0.2	0.5	0.1	0.4
Solid cattle/sheep	0.3	0.3	0.3	0.25	0.2
Solid poultry	0.3	0.4	0.5	0.3	0.3
Liquid cattle	0.3	0.4	0.5	0.3	0.4
Liquid swine	0.2	0.3	0.4	0.2	0.3
Liquid biosolids	0.3	0.4	0.5	0.3	0.4

Source: Adapted from Barry et. al., University of Guelph, 2000. Available N in manure = total manure N applied x available N from Table 4.

[1] Assumes a spring-planted crop.

[2] Accounts for ammonia loss to atmosphere and mineralization of organic N.

[3] For manure incorporated within 3 days, use (incorporated value + non incorporated value) ÷ 2.

Cover crops can help retain the nitrogen from manure applied in the summer or early fall.

Field trials with specific livestock manure types to determine how much nitrogen would be available to crops the following year has resulted in Table 9–12, *Estimate of Available Nitrogen From Late Summer- and Fall-Applied Manure*, this page. To estimate the amount of nitrogen available to the crop, multiply the amount of manure nitrogen applied to the field by the availability factor appropriate for the manure type and application timing. For example, if 45,000 L/ha (4,000 gal/acre) of liquid hog finishing manure is applied in late summer, supplying 285 kg/ha (256 lb/acre) of total N, reduce the N fertilizer application to the following crop by 57 kg/ha (51 lb/acre) (285 lb/acre total N x 0.2 availability factor).

Table 9–12 accounts for the volatilization of ammonium-N into the air, the mineralization of organic-N and the loss of nitrate through denitrification or leaching. A large part of the ammonium-N will be lost to the air if manure is left on the soil surface so the proportion of nitrogen available to the crop is greater with incorporated manure. Assumptions have been made concerning the proportion of nitrogen in the ammonium and organic forms (see Table 9–9, previous page) and the availability of the organic nitrogen. Urea has been included as an example of how fertilizer nitrogen availability compares with that of manure. These factors can be used with the results of a manure analysis or the values in Table 9–13, *Typical Manure Analysis by Livestock Type*, opposite page, to estimate nitrogen availability.

Manure Analysis

Manure analysis is necessary because the quantities of nutrients contained in manure will vary from farm to farm, especially the phosphorus and potash components. Type of livestock, ration, bedding, added liquids and storage system all affect the final nutrient analysis. Phosphorus tends to be concentrated in the solids, while potassium levels tend to be higher in the liquid portion, therefore the level of agitation will affect nutrient levels being applied to a field. Fertilizer adjustments based on a manure analysis will be more accurate than those based on average values.

Above-average levels of nitrogen, phosphorus or trace elements in manure may be an indication that dietary levels are higher than required. Amino acid balancing for nitrogen, reducing the amount of phosphorus in the mineral supplements or the addition of phytase (an enzyme that increases phosphorus efficiency in the animal) may be methods that can help reduce these nutrients in manure. A livestock nutritionist should be consulted before making ration changes.

Manure analysis is available from several laboratories in Ontario. Sample after complete agitation or thorough mixing each time the storage is emptied (i.e., spring and fall) and send the sample for analysis. After several analyses, a trend in results should become evident. As well, sample any time there are changes in ration or other management factors.

When sending a sample to the lab, fill a plastic jar about half-full, secure the top, place in a plastic bag and store in a cool place until shipping. Analysis should include total nitrogen, ammonium-nitrogen (NH_4-N), phosphorus, potassium and dry matter. Ontario labs return analysis results with percentages for nitrogen, phosphorus, potassium and dry matter, as well as mg/kg (or ppm) of ammonium nitrogen. On most reports, percentages of phosphorus and potassium from manure

Table 9–13. Typical Manure Analysis by Livestock Type
(fresh weight basis)

				Total Nutrient Content (as-is basis)		
DM Range	Solid/ Liquid	Ave. DM %	Total N %	NH_4-N[1] %	P %	K %
Hog						
Solid average	S	30	0.90	0.27	0.46	0.56
Liquid average	L	3.7	0.40	0.27	0.13	0.18
Finisher	L	7.6	0.64	0.45	0.23	0.30
Weaners	L	3.0	0.33	0.23	0.14	0.16
Sow	L	2.2	0.26	0.17	0.06	0.13
Dry sows	L	1.9	0.27	0.23	0.10	0.11
Dairy						
Solid average	S	25	0.59	0.12	0.17	0.49
30% +	S	39	0.65	0.08	0.17	0.53
18%–30%	S	21	0.57	0.13	0.16	0.48
Liquid average	L	8.4	0.35	0.15	0.08	0.24
10%–18%	L	14	0.49	0.18	0.14	0.32
6%–10%	L	8.0	0.36	0.16	0.07	0.24
2%–6%	L	4.4	0.24	0.12	0.05	0.19
Beef						
Solid average	S	28	0.74	0.10	0.24	0.57
30% +	S	38	0.95	0.10	0.38	0.74
18%–30%	S	24	0.63	0.11	0.16	0.48
Liquid average	L	7.9	0.31	0.13	0.08	0.22
10%–18%	L	15	0.48	0.17	0.13	0.33
6%–10%	L	7.8	0.33	0.15	0.08	0.20
2%–6%	L	3.8	0.21	0.12	0.05	0.15
Runoff						
0%–2%	L	0.7	0.05	0.03	0.01	0.09
Horses						
Average	S	37	0.50	0.07	0.15	0.43
Sheep						
Average	S	34	0.80	0.23	0.28	0.78
80% +	S	85	3.36	0.21	1.69	1.74
Poultry						
Layers	S	34	1.93	0.78	0.89	0.80
Pullets	S	48	3.14	0.72	1.36	1.35
Broilers	S	68	3.09	0.44	1.33	1.52
Liquid average	L	11	0.82	0.56	0.30	0.30
Biosolids						
Aerobic	L	2.0	0.12	0.01	0.06	0
Anaerobic	L	4.4	0.28	0.08	0.14	0
Dewatered	S	32	3.76	0.34	1.31	0.11

[1] To convert from % to ppm, multiply by 10,000.

are converted to phosphate and potash equivalents, and commercial fertilizer reductions are often reported.

Details for interpreting a manure analysis are shown in *Calculating Available Nutrients from Spring-Applied Manure Using a Manure Analysis*, next page.

Information from a manure analysis, plus knowledge of the conditions at the time the manure was applied, can be used to provide a more precise estimate of the available nutrients in the manure applied to your fields.

Nutrient Losses From Manure

There are two nitrogen components in manure. Ammonium-nitrogen makes up the largest percentage of the nitrogen in liquid manure with approximate percentages listed by livestock type in Table 9–9, *Approximate Ammonium-Nitrogen as a Percentage of Total Nitrogen in Various Manure Types*, on page 165. The organic-N component is available over time as the organic matter breaks down, similar to a slow-release nitrogen fertilizer. About 20%–30% of the organic nitrogen component of manure is assumed to be available to a growing crop in the year of application. The percentage is generally higher in poultry and lower for ruminant livestock manure.

Ammonium-N is immediately available to a growing crop but is also easily lost to volatilization unless incorporated soon after application. Soil moisture and weather conditions will determine how quickly and how much loss to expect. These losses are highest on sunny, warm days, when soils are dry; losses are lowest when conditions are overcast and cold (<10°C), when soils are moist or during rainy periods. Table 9–10, *Estimated Percentage of Ammonium-Nitrogen Lost Due to Weather and Soil Conditions*, on page 165, gives estimated losses due to weather and soil conditions only for the ammonium-nitrogen component of manure. With manure applied in late fall, the losses are low since cooler temperatures slow down microbial action in soil, which minimizes conversion. Losses can be high due to runoff from late fall applications, especially when not incorporated. Denitrification and leaching losses of nitrogen are dealt with in *Nitrogen Risk Mitigation*, on page 172.

Table 9–11, *Estimated Percentage of Organic Nitrogen Available in Year of Application*, opposite page, gives estimated nitrogen available from the organic nitrogen portion of the manure based on livestock type.

Long-Term Value of Manure

The long-term availability of phosphorus (P), potassium (K), magnesium, zinc or manganese from previous manure applications is best estimated by soil testing. Application of large quantities of manure over time can result in high levels of available P and K in soils. Manure also provides organic matter and other plant nutrients to the soil that will contribute to improved soil physical structure and buffering capacity.

Calculating Available Nutrients from Spring-Applied Manure Using a Manure Analysis

Keep the same units throughout the calculation. Some reports will provide ammonium-N contents in ppm (mg/kg, mg/L), while the other numbers are in percentages. To convert ppm to percentage, divide by 10,000.

Available Nitrogen[1]		**Available Phosphate**[2]		**Available Potash**[2]	
A. Total Nitrogen		**H.** Total Phosphorus		**K.** Total Potassium	
B. Ammonium-N		**I.** Available Phosphorus (H x 0.4)		**L.** Available Potassium (K x 0.9)	
C. Organic N[3] (A–B)		**J.** Available Phosphate (I x 2.29)		**M.** Available Potash (L x 1.2)	
D. Ammonium Losses (B x factor from Table 9–10 on page 165)					
E. Available Ammonium (B–D)					
F. Available Organic N (C x factor from Table 9–11 on page 166)					
G. Total Available N (E+F)[4]					

For values in percent:

To get:	**multiply by:**
kg/1,000 L	10
lb/1,000 gal	100
kg/tonne	10
lb/ton	20

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[1] Available nitrogen is determined by subtracting the ammonia losses to the air from the ammonium-N applied and adding the mineralization from the organic N portion of the manure.

[2] Calculate reductions in fertilizer phosphate and potash by determining the available portion of the total P and K in the manure (40% for phosphorus and 90% for potassium) and multiplying by a factor to convert from the elemental form to the oxide form (fertilizer nutrients are expressed in the oxide form). In the year of application, 40% is available; another 40% is available in following year.

[3] Organic N will also give an N credit for several years after application: 10% in 2nd year, 5% in 3rd year, x 2% in 4th year.

[4] To estimate the available N from summer or fall applications of manure, multiply the Total N content by the appropriate factor in Table 9–12, *Estimate of Available Nitrogen From Late Summer- and Fall-Applied Manure*, on page 166.

Example: Dairy manure is spring applied at (5,000 gal/acre) under cool, dry conditions ahead of planting corn (incorporated within 3 days); DM content is 7%; total N is 0.65%; ammonium N is 0.35%; total P is 0.2%, total K is 0.3% (as-is basis)

Available Nitrogen		**Available Phosphate**		**Available Potash**	
A. Total Nitrogen	0.65	**H.** Total Phosphorus	0.2	**K.** Total Potassium	0.3
B. Ammonium-N	0.35	**I.** Available Phosphorus (0.2 x 0.4)	0.08	**L.** Available Potassium (0.3 x 0.9)	0.27
C. Organic N (0.65 – 0.35)	0.30	**J.** Available Phosphate (0.08 x 2.29)	0.18	**M.** Available Potash (0.27 x 1.2)	0.32
D. Ammonium Losses (0.35 x 0.38)	0.13				
E. Available Ammonium (0.35 – 0.13)	0.22				
F. Available Organic N (0.30 x 0.20)	0.06				
G. Total Available N (0.22 + 0.06)	0.28				
Nutrients lb/1,000 gallons	28		18		32

An electronic version of this worksheet can be found in the OMAFRA NMAN software or as a spreadsheet at www.gocorn.net.

Most of the available nitrogen in manure is used by the crop or is lost during the first growing season following application. The remaining organic nitrogen becomes available in small, diminishing quantities in the succeeding years. Generally, the amount of residual nitrogen from one application of liquid manure is too small to make a practical difference in nitrogen recommendations for a crop. However, where solid manure is applied regularly to the same field, there can be significant residual nitrogen available for a crop. Use regular soil testing for P and K to measure residual levels of these nutrients from manure applications.

Crop Requirements

Soil test results and yield goals will determine the maximum economic manure application rate and/or additional fertilizer requirements. Often soil test levels on livestock farms indicate that soil fertility levels are high enough that we do not expect any response to additional fertility.

An alternative to determining application rates from soil test values is to apply manure based on the amount of nutrients removed by a crop and then match phosphorus and/or nitrogen from manure to determine an application rate. In theory this method should keep soil fertility levels constant. Table 9–14, *Average Nutrient (N, P, K) Removal by Common Field Crops*, next page, will help determine the average nutrient removal for various crops.

If manure is applied to meet the entire nitrogen requirements of a corn crop, there will usually be more P and K applied than the crop will remove, and soil test levels will increase. For liquid manure, an application goal of two-thirds to three-quarters of the nitrogen requirements for a corn crop is a reasonable compromise. The high carbon content in the bedding materials of solid manure makes the release of nitrogen much less predictable. Due to difficulty in uniform application for both solid and liquid manure, starter fertilizer is still recommended unless soil test results indicate that there will be no economic response to additional fertilizer.

Take into account residual nitrogen from legume crops when determining additional nitrogen needs from manure or fertilizer (see Table 9–7, *Adjustment of Nitrogen Requirement, Where Crops Containing Legumes Are Plowed Down*, on page 162). Apply manure to cereal crops, soybeans or canola with caution, since too high a rate will increase the potential for lodging. For summer application to standing crops such as corn or forages, keep rates below 45,000 L/ha (4,000 gal/acre) or 55–65 kg/ha (50–60 lb/acre) ammonium nitrogen. Complete application to forages as soon as possible after harvest to avoid wheel track damage to new growth and potential nitrogen burn to new leaf growth. Older forage stands with higher grass content will benefit most from the manure nitrogen. Do not apply concentrated manures with high ammonium-nitrogen levels (e.g., liquid layer poultry or concentrated finisher hog manure) into standing crops.

Soil compaction is a problem for many growers and is the main reason that late summer or early fall manure application is so popular. Compaction leads to poor drainage and decreased aeration. The best way to reduce or avoid soil compaction from manure application is to spread manure when the soil is dry. Loads should stay below 4.5 tonnes (5 tons) per axle. Spring spreading is often carried out on fields where soils are too wet, and it is not unusual for strips of stunted crops to reveal the location of wheel traffic from application equipment.

Manure and No-Till

Manure is still one of the factors that make livestock farmers think twice about no-till systems. When manure is utilized in a no-till system, there has to be a compromise — some tillage or some loss of nutrients from manure.

A few points to consider when applying manure in a no-till system:

- What is the goal for the manure applied? Is the organic matter from manure more important, or are the nutrients the focal point? If nutrients, especially nitrogen, are the important feature, decide which is more important: limited pre-planned tillage or some loss of nitrogen.
- Manure type will influence how much nitrogen is potentially lost. Solid manure has a smaller percentage as ammonium nitrogen, therefore less total nitrogen will be lost. The higher organic nitrogen component is less available but releases nitrogen longer.
- Where manure is surface applied, a majority of the ammonium portion of the manure will be lost. Rain (i.e., 12 mm gentle infiltrating) shortly after application will incorporate some of the ammonium.
- A manure analysis is important.
- Plan manure application well and consider crop rotation, especially in a no-till system where nutrients are not incorporated through tillage.
    - Manure applied after wheat or spring cereal harvest is the best option. Shallow tillage with a disc when soils are dry will help incorporate cereal straw and manure and could also incorporate cover crop seed. Minimal tillage will not disturb earthworm channels, and nitrogen will help with straw breakdown.
    - Apply manure to corn when soils are dry to avoid rutting and compaction. Consider side-dress applications to standing corn.

Table 9–14. Average Nutrient (N, P, K) Removal by Common Field Crops

	Removal kg/tonne (lb/bushel)				Removal in DM[3] kg/tonne (lb/ton)		
Grains, Oilseeds	**N[2]**	**P_20_5**	**K_20**	**Silage/Forage Crops**	**N[4]**	**P_20_5**	**K_20**
Grain corn	11.5–18 (0.65–1.0)	6.6–7.9 (0.37–0.44)	4.6–5.2 (0.26–0.30)	Corn silage	11–15 (22–30)	4.6–6.8 (9.3–14)	8.3–15 (17–30)
Soybeans	62–67 (3.7–4.0)	13–15 (0.80–0.88)	51.1 (1.4)	Legume haylage	27–37 (53–73)	5.3–7.9 (11–16)	22–35 (45–71)
Winter wheat (grain only)	19–21 (1.15–1.25)	9.1–10.4 (0.55–0.63)	6.0 (0.36)	Mixed haylage	23–34 (46–68)	5.2–7.8 (10–16)	22–35 (45–71)
Winter wheat (grain + straw)[1]	31–34 (1.9–2.1)	11–12 (0.68–0.75)	21–34 (1.25–2.0)	Grass haylage	16–27 (32–55)	4.9–7.8 (9.8–16)	20–36 (41–72)
Barley (grain only)	18–23 (0.87–1.1)	8.0 (0.40)	5.3–7.2 (0.25–0.35)	Legume hay	22–33 (45–66)	5.2–8.0 (10–16)	21–35 (41–70)
Barley (grain + straw)	26–31 (1.2–1.5)	10–1.4 (0.5–0.6)	21–31 (1.0–1.5)	Mixed hay	17–27 (34–55)	5.0–0.2 (10–14)	17–30 (34–59)
Oat (grain only)	18–24 (0.63–0.80)	7.5 (0.25)	5.8 (0.19)	Grass hay (1st cut)	13–23 (26–45)	4.4–7.0 (8.8–14)	14–28 (28–56)
Oat (grain + straw)	27–34 (0.9–1.5)	12.4 (0.42)	35–43 (1.2–0.5)	Mixed hay (2nd cut)[5]	25–36 (51–72)	5.7–7.8 (11–16)	20–32 (40–64)
Winter rye (grain only)	19–22 (1.1–1.2)	6.1–8.2 (0.3–0.5)	6.25 (0.35)				
Winter rye (grain + straw)	30 (1.7)	10–15 (0.6–0.8)	18–43 (1.0–2.4)				
Dry beans	42 (2.5)	14 (0.83)	14 (0.83)				
Canola	40–44 (2.0–2.2)	22–27 (1.1–1.3)	11–13 (0.55–0.67)				

Source: Based on Ontario data where possible and general North American data where local data was insufficient.
Forage crop data from Agri-Food Laboratories, Guelph. (1990–95).

[1] The range of P and K in cereal straw and dry hay will be reduced (leached) if heavy or frequent rainfall occurs while the material is in windrows in the field.

[2] Soybeans, dry beans and forage legumes receive most of their nitrogen from the air.

[3] To convert from "as harvested" to "dry matter yield," multiply the as-harvested yield by the dry matter content of the crop (e.g., 25T corn silage x 40% DM (60% moisture) = DM yield of 10T)

[4] The range of N removal is large, because hay is harvested at a wide range of protein levels. Generally, higher protein means lower yield.

[5] 2nd cut generally has a higher legume content.

  - Manure applied ahead of soybean planting is an option where varieties are chosen with some resistance to white mould.
  - Liquid manure applied to forages is a good option. Apply manure as soon as possible after harvest, before re-growth. Application to older grass-alfalfa stands will give the largest nutrient benefit.
  - Avoid applying liquid manure to snow-covered perennial forages, since ice can form under the manure, resulting in increased winterkill.
- A nutrient analysis is important, regardless of which crop the manure is applied to, so that commercial fertilizer application can be balanced with what was provided in the manure.
- Too high a rate of surface applied manure can lead to slower soil warm-up in spring or sealing of soil. Calibrate application equipment to ensure an accurate rate.

Calibrating Application Equipment

Calibrating manure application equipment is essential. Several methods can be used to measure spreading rates. Weighing a load of manure and measuring the area that load covers is one method of estimating the rate of application. Weigh solid manure by placing plastic sheets on the ground and liquid manure by using straight-walled pails for measuring depth of application. Consider overlap, especially in irrigation systems. Table 9–15, *Calibrating Manure Spreaders*, opposite page, gives an estimate of application rates, while Table 9–16, *Densities of Different Types of Manure*, opposite page, distinguishes

Table 9–15. Calibrating Manure Spreaders

Solid Manure Calibration[1]		Liquid Manure Calibration[2]				
kg of Manure	Application Rate	Depth of Manure in Pail		Application Rate		
					Imp.	U.S.
(per sheet)	t/ha[3]	in.	mm	L/ha	gal/acre	
0.5	3.6	1/10	2.5	25,000	2,225	2,675
0.9	7.2	1/8	3.2	32,000	2,850	3,420
1.4	10.8	1/4	6.4	64,000	5,520	6,845
1.8	14.3	4/10	10	100,000	8,900	10,690
2.3	17.9	1/2	12.7	127,000	11,305	13,580
3.2	25.1	6/10	15.0	150,000	13,355	16,040
4.5	35.8	3/4	19.1	191,000	17,000	20,420
6.8	53.8	1	25.4	254,000	22,610	27,160

[1] Using a 122 cm x 102 cm sheet (40 in. x 48 in. plastic feedbag).

[2] Using a straight-walled pail.

[3] Tons per acre = tonnes per hectare x 0.45.

between the densities of different types of manure. For further detail, visit the OMAFRA website at www.ontario.ca/crops.

Environmental Concerns With Manure

Using manure to meet but not exceed crop nutrient needs will help minimize nutrient losses to the environment. Take additional care to avoid the movement of manure into streams from erosion, surface and tile runoff. Contamination of the environment is prohibited under the *Environmental Protection Act*, the *Ontario Water Resources Act*, and the federal *Fisheries Act*. In addition, there are specific requirements for manure application under the *Nutrient Management Act* and Regulation 267/03. See the most recent updates of the regulation, or contact an OMAFRA Nutrient Management Specialist, for more details.

Application to fields with steep slopes or impermeable soils can cause manure runoff when application rates are too high. For some soil types, several applications at lower rates may be necessary. Spreading manure in the winter and early spring is not recommended because of the potential for runoff to surface water and nutrient accumulations in water-ponded areas. Although winter application should not be part of a nutrient management plan, there are some mild spells where field application accompanied by immediate incorporation is possible. In years when winter spreading may be necessary, take care to select fields with the lowest risk of runoff to surface water.

Table 9–16. Densities of Different Types of Manure

Manure Type	Weight per Cubic Metre	Weight per Cubic Foot	Weight per Litre	Weight per Bushel
Liquid	1,000 kg	62 lb	1.0 kg	80 lb
Semi-solid	960 kg	60 lb	0.9 kg	76 lb
Thick solid	800 kg	50 lb	0.8 kg	64 lb
Light solid	560 kg	35 lb	0.6 kg	45 lb
Dry poultry litter	400 kg	25 lb	0.4 kg	30 lb

1 bushel = 1.25 cubic feet

Rain can cause organic nitrogen to wash into streams if manure has been applied to unprotected cropland. Phosphorus attached to soil particles can be carried to streams by soil erosion. Conservation practices can reduce the chances of nutrients polluting waterways.

Do not apply manure near watercourses. Runoff potential is influenced by field slope and soil texture. Flow in tile drains can become contaminated if manure enters a catchbasin or travels through soil cracks to the tiles. To minimize the risk of contaminated tile flow, apply at low rates when the tiles are not running, or lightly till the field before manure application to break any cracks or worm holes.

Applications of nutrients contained in manure or fertilizer in excess of crop requirements can result in contamination of groundwater, particularly on shallow soils over bedrock, soils with a water table close to the surface or very sandy soils where leaching is a concern. Groundwater contamination can occur by mass flow through cracks and holes to groundwater or through leaching of nitrates through the soil. Contamination can also occur if manure seeps directly into inadequately protected water wells. Manure should not be applied within 15 m (50 ft) of drilled wells, 30 m (100 ft) of dug wells or 100 m (330 ft) from a municipal well (Nutrient Management Regulations).

Large livestock operations on small land bases pose special challenges. To avoid over-application of nutrients, especially on fields near the barn, complete a nutrient management plan. It may be necessary to sign agreements with neighbouring farms to ensure the availability of fields for proper manure spreading.

Detailed information about maximum application rates and setbacks from surface water or water wells can be found in the NMAN software or OMAFRA Publication 818, *Nutrient Management Workbook*, available at www.ontario.ca/crops.

Nitrogen Risk Mitigation

The nitrogen cycle, with its many forms of nitrogen, is a complicated process that is influenced by many factors including weather, soil and physical, chemical and biological processes. Use the optimum amount of nitrogen, keeping in perspective that any nitrogen not used has the potential to leach below the root zone, volatilize into the atmosphere or denitrify (potentially to nitrous oxide — a greenhouse gas).

Nitrate that could potentially leach out of the rooting zone includes nitrogen that is applied in excess of crop removal and nitrogen from manure or biosolids applied during the non-growing season (late summer or fall). In Ontario, most of the drainage to groundwater occurs during the late fall to early spring period, when precipitation exceeds evaporation. On sandy, well-drained soils, much of the nitrate present in the fall could be leached into groundwater if drainage occurs. On heavier soils, more of the loss will be through denitrification. Minimizing the amount of soil nitrate present in the fall will reduce both types of loss.

Management practices to reduce the risk of nitrate losses include:

- growing cover crops whenever manure is applied in late summer or early fall
- timing nitrogen applications close to crop nitrogen uptake
- matching total nitrogen applications to crop requirements

Phosphorus Risk Assessment

The risk of surface water contamination by phosphorus may be increased at higher soil test phosphorus levels. However, since phosphorus binds tightly to soil particles, the movement of soil from a field by erosion is also a major factor in determining the risk of surface-water contamination. Because of this, the risk of surface-water contamination by phosphorus cannot be based on a soil-test phosphorus level alone.

The risk of phosphorus contamination to surface water increases when soil test results indicate that no additional phosphorus is required to achieve maximum economic yield, but manure nutrients will still be applied. Phosphorus in surface-water sources increases eutrophication or aquatic plant growth, which leads to oxygen fluctuations and decreased ability for the water source to support aquatic life. To address the environmental risk of additional phosphorus application when soil test levels are adequate, a phosphorus index has been developed. The phosphorus index results in wider phosphorus-free buffers adjacent to water courses when there is a significant risk of nutrient/soil runoff and when phosphorus fertility levels are also high.

The phosphorus index considers:

- soil erosion potential
- water runoff potential
- phosphorus soil fertility levels
- fertilizer and manure application method and rate

For more information on phosphorus risk assessment, see the OMAFRA Factsheet, *Determining The Phosphorus Index for a Field,* Order No. 05-067, Publication 818, *Nutrient Management Workbook*, the NMAN software, or visit the website at www.ontario.ca/crops.

Biosolids and Residuals Use on Agricultural Land

Biosolids are nutrient-rich, processed organic materials derived from municipal wastewater treatment processes. They usually contain mineral and organic nitrogen, phosphorus, potash, organic matter and micronutrients such as zinc, magnesium and copper. The use of biosolids as part of a farm nutrient management package can reduce the demand for commercial fertilizers, improve soil fertility and enhance soil structure, moisture retention and permeability. Biosolids are ideal for crops such as corn, soybeans, cereals and forage crops.

Residuals include pulp-and-paper-mill fibre residuals, grain processing by-products and many other organic-based wastes, as well as some inorganic materials such as lime rejects from the sugar-processing industry. Each type of waste has unique characteristics that have the potential to benefit soil quality and/or crop production. Some may have limitations, e.g., sewage biosolids are very low in potassium. Be informed about the nutrient content, availability and possible negative impacts of biosolids and residuals use.

Biosolids and residuals land application is regulated under Part V of the *Environmental Protection Act*. The use of biosolids and residuals on agricultural land is regulated by the Ontario Ministry of the Environment. The *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land,* March 1996, sets out the guidelines related to biosolids and residuals quality, the application site criteria and the application of these materials on agricultural land. A Certificate of Approval is required before land application of any regulated waste material can occur. When properly used, biosolids and residuals can provide a valuable supplementation to a farm nutrient management program.

Table 9–17. Fertilizer Materials – Primary Nutrients

Nitrogen Materials	**Form**	**% Nitrogen (N)**	**Salt Index[1]**
Ammonium nitrate	dry	30 to 34	15.3
Calcium ammonium nitrate	dry	27	15.3
Urea	dry	45 to 46	8.1
Ammonium sulfate	dry	21	16.3
Urea-ammonium nitrate	liquid	28	11.3
Anhydrous ammonia	liquid[2]	82	2.9
Phosphate Materials		**% Phosphate (P_2O_5)**	
Single superphosphate	dry	20	2.0
Triple superphosphate	dry	44 to 46	1.1
Monoammonium phosphate	dry	48 to 52	2.0
Diammonium phosphate (18-46-0)	dry	46	2.3
Ammonium polyphosphate (10-34-0)	liquid	34	2.3
Potash Materials		**% Potash (K_2O)**	
Muriate of potash	dry	60 to 62	9.7
Sulfate of potash	dry	50	4.3
Sulfate of potash magnesia (11% Mg)	dry	22	9.9
Potassium nitrate (13-0-44)	dry	44	6.1

[1] Expressed per unit (100 lb) of nutrient.

[2] Liquid under pressure.

Table 9–18. Fertilizer Materials – Secondary and Micronutrients

Magnesium (Mg)	
Dolomitic limestone	6%–13% Mg
Epsom salts (magnesium sulfate)	10.5% Mg
Sulfate of potash magnesia	11% Mg
Boron (B)	
Sodium borate	12%–21% B
Solubor	20.5% B
Copper (Cu)	
Copper sulfate	13%–25% Cu
Copper chelates	5%–13% Cu
Manganese (Mn)	
Manganese sulfate	26%–28% Mn
Molybdenum (Mo)	
Sodium molybdate	39% Mo
Zinc (Zn)	
Zinc sulfate	36% Zn
Zinc chelates	7%–14% Zn
Zinc oxysulfate	18%–36% Zn

Fertilizer Materials

Nitrogen fertilizer materials are available in dry or liquid forms. Although there are some limitations to the use of these materials (see *Toxicity of Fertilizer Materials*, next page), in most cases, the different sources will produce equal yields. The choice of material should therefore depend on availability, equipment for handling and cost per kilogram of nitrogen, plus the cost of application.

First, calculate the cost per kilogram of nitrogen for various sources delivered to your farm. Using the rate of application, determine the cost per hectare. Add to this, the cost of application per hectare before deciding which nitrogen source to use.

Where separate additions of nitrogen are referred to in the recommendations, kilograms of elemental nitrogen, not kilograms of fertilizer materials, are used. Table 9–17, *Fertilizer Materials – Primary Nutrients*, this page, and Table 9–18, *Fertilizer Materials – Secondary and Micronutrients*, this page, show the percentage of fertilizer nutrient contained in different materials.

Various fertilizer companies have premixes available containing one or more micronutrients in addition to the micronutrient sources listed in Table 9–18, above.

A wide range of liquid fertilizers is used in Ontario. While these are generally more expensive per unit of nutrient than dry granular fertilizers, liquid fertilizers are easier to handle and can be metered and placed more precisely. Characteristics of the most commonly used liquid fertilizers are included in Table 9–19, *Densities of Common Liquid Fertilizers*, next page.

Soluble Salts in Farm Soils

High concentrations of water-soluble salts in soils can prevent or delay the germination of seeds and can kill established plants or seriously retard their growth.

Ontario soils are naturally low in soluble salts. Soluble salts therefore rarely cause a problem in crop production and are not routinely measured in soil tests.

Soluble salts in soils can result from excessive applications of fertilizers and manures, runoff of salts applied to roads and chemical spills on farmland. High concentrations of soluble salts in or near a fertilizer band can cause serious reductions in early plant growth without seriously affecting the salt concentrations in the remainder of the soil. A given amount of salt in a soil provides a higher salt concentration in soil water, if the amount of water is small.

Table 9–19. Densities of Common Liquid Fertilizers

Analyses	Weight/ U.S. Gallon (lb)	Weight/Imp. Gallon (lb)	Weight/ Litre (lb)	Weight/ Litre (kg)	Imp. Gallons/ Tonne	US Gallons/ Tonne	Litres/ Tonne
8-25-3	11.11	13.35	2.94	1.334	165.1	198.4	749.9
6-18-6	10.69	12.85	2.83	1.284	171.6	206.2	779.0
3-11-11	10.45	12.55	2.76	1.251	175.7	211.0	798.8
9-9-9	10.49	12.60	2.77	1.256	175.0	210.2	795.9
7-7-7	10.41	12.5	2.75	1.247	176.4	211.8	801.7
6-24-6	11.07	13.30	2.93	1.329	165.8	199.2	752.4
9-18-9	11.07	13.30	2.92	1.325	165.8	199.2	755
5-10-15	10.7	12.85	2.83	1.252	171.6	206.0	799
2-10-15	10.62	12.75	2.81	1.275	172.9	207.6	784.6
10-34-0	11.5–11.74	14.0–14.1	3.08–3.10	1.397–1.406	157.5–156.4	189.2–187.8	715.8–711.2
28%	10.65	12.8	2.82	1.279	172.2	207.0	781.8
Aqua	7.49	9	1.98	0.898	245	294.3	1,113.4
54% phos. acid	13.15	15.8	3.48	1.579	139.5	167.7	633.5

1 Imperial gallon = 1.201 US gallons = 4.546 litres

1 US gallon = 0.8326 Imperial gallons = 3.785 litres

Soluble salts also interfere with the uptake of water by plants. For these reasons, plant growth is most affected by soluble salts in periods of dry conditions at planting.

Soluble salts can be measured readily in the laboratory by measuring the electrical conductivity of a soil water slurry. The higher the concentration of water soluble salts, the higher the conductivity. Table 9–20, *Soil Conductivity Reading Interpretation*, this page, provides an interpretation of soil conductivity readings.

Toxicity of Fertilizer Materials

All fertilizer salts are toxic to germinating seeds and to plant roots if applied in sufficient concentration near the seed. Fertilizers vary in toxicity per unit of plant nutrient due to:

- differences in the amount of salts contained in the fertilizer per unit of plant nutrient
- differences in the solubility of the salts in the soil
- the presence of specific materials or elements that are particularly toxic (e.g., ammonia and boron) Many nitrogen fertilizers, despite relatively low salt index, release free ammonia into the soil.

Nitrogen Fertilizers

Ammonium nitrate, monoammonium phosphate and ammonium sulphate are similar in toxicity and much safer than anhydrous ammonia, aqua ammonia or urea. Diammonium phosphate is more toxic than monoammonium phosphate but less toxic than urea. Use lower rates of urea, or increase the distance between the seed and fertilizer band, particularly with sensitive seeds such as beans or peas, and on coarse-textured soil (sand and sandy loam).

Because anhydrous ammonia and aqua ammonia are extremely toxic fertilizers, they should not be placed near seeds. It is preferable to make preplant applications crossways to the direction in which the crop will be planted. Stand reductions may still occur over the band in very dry soils or if planting takes place too soon after application.

Urea is toxic when banded with or near the seed but is safe when broadcast at rates normally used. Fertilizers containing more than half as much nitrogen as phosphate frequently contain urea.

Table 9–20. Soil Conductivity Reading Interpretation

Conductivity "salt" reading (millisiemens/cm)	Rating	Plant Response
0–0.25	L	Suitable for most plants with recommended amounts of fertilizer.
0.26–0.45	M	Suitable for most plants with recommended amounts of fertilizer.
0.46–0.70	H	May reduce emergence and cause slight-to-severe damage to salt-sensitive plants.
0.71–1.00	E	May prevent emergence and cause slight-to-severe damage to most plants.
1.00	E	Expected to cause severe damage to most plants.

Fertilizer Calculations — An Example

Based on soil test results and N calculator, a farmer requires 120 lb of N, 18 lb P_2O_5 and 30 lb K_2O to grow a crop of corn. A liquid starter fertilizer (5 gal/acre 6-24-6) will be included.

Step 1: Determine starter contribution
Liquid fertilizer with a blend of 6-24-6 and a density of 13.3 lb/gal is applied at 5 Imperial gal/acre.

The fertilizer contains 6% N, 24% P_2O_5 and 6% K_2O. The application rate is 5 gal/acre x 13.3 lb/gal = 66.5 lb/acre.

N 66.5 lb/acre x 6/100 = 4 lb/acre

P_2O_5 66.5 lb/acre x 24/100 = 16 lb/acre

K_2O 66.5 lb/acre x 6/100% = 4 lb/acre

Step 2: Determine balance required
120 – 4 = 116 lb N/acre still required

18 – 16 = 2 lb P_2O_5/acre (small enough difference to ignore)

30 – 4 = 26 lb K_2O/acre still required

Step 3: Determine supplemental fertilizer to meet balance of crop requirements
Fertilizer rates are determined by dividing the nutrient requirement by the percent nutrient in the fertilizer. If the supplemental fertilizer is to be a blend of urea plus potash, the calculations will be:

116 lb N/acre ÷ 0.46 (or 46%) = 252 lb/acre urea (46-0-0)

26 lb K_2O/acre ÷ 0.62 (or 62%) = 42 lb/acre muriate of potash (0-0-60)

Total application rate = 252 + 42 = 294 lb/acre of blended fertilizer

For more details on calculating nutrient requirements and fertilizer blends, see OMAFRA Publication 611, *Soil Fertility Handbook*.

Phosphate Fertilizers

Phosphate fertilizers are usually low in toxicity due to a large portion of the phosphate being precipitated in the soil before it can reach the plant roots. The concentration of phosphorus in soil solution at any one time is very low. No limit is normally set for the safe rate at which phosphates may be applied with, or near, the seed of field-grown crops.

Diammonium phosphate is more toxic than other phosphate fertilizers. See *Nitrogen Fertilizers*, opposite page.

Potash Fertilizers

Muriate of potash (KCl) is the most common source of potassium in fertilizers and is less toxic per unit of plant nutrients than most nitrogen fertilizers.

Sulphate of potash (K_2SO_4) is slightly less toxic than muriate of potash. Sulphate of potash-magnesia has approximately the same toxicity per unit of potassium as muriate of potash. Potassium nitrate is one of the safer sources of potassium.

Table 9–21, *Maximum Safe Rates of Nutrients*, next page, provides the maximum safe rates of nutrients for various crop scenarios. The safe rates listed in this table are for practices occurring singly. If two or more fertilizer applications are combined, the additive effect may cause damage to the crop even though the individual applications are below the threshold for injury.

Fertilizers Containing Micronutrients

Fertilizers containing micronutrients (boron, copper, iron, manganese or zinc) are more toxic than the same grades without micronutrients; reduce maximum safe rates. Boron is particularly toxic and should not be banded.

Guidelines for Safe Rates of Nutrients Applied at Seeding

Fertilizer toxicity varies widely, depending on the amount of soil moisture. Injury will occur most frequently on light-textured (sandy or gravelly) soils low in organic matter and with dry weather. To ensure completely safe rates of banded fertilizer for all seeding conditions would require extremely low rates of application. The maximum safe rates suggested here will most likely reduce or delay germination, or retard growth in up to 10% of the cases where they are used. It is generally advisable to use lower rates of fertilizer at seeding than those listed in Table 9–21, *Maximum Safe Rates of Nutrients*, next page.

If fertilizer requirements are high, it may be better to broadcast most of the fertilizer required and to band only a small portion at seeding. Fertilizers containing the micronutrients boron, copper, iron, manganese and zinc are more toxic, and the safe rates recommended will be lower than those shown in this table.

Table 9–21. Maximum Safe Rates of Nutrients

Crop	N (kg/ha)	N+K$_2$O (kg/ha)
Spring oat and barley (fertilizer with seed)		
Sands, sandy loam		
Urea (46-0-0)	10	30
Di-ammonium phosphate (18-46-0)	20	35
Other fertilizers	35	55
Loams, silt, clay loams		
Urea (46-0-0)	10	30
Di-ammonium phosphate (18-46-0)	30	55
Other fertilizers	45	70
Winter wheat, triticale or barley (fertilizer with seed)		
All soils		
Urea (46-0-0)	0 (fall)	0 (fall)
Di-ammonium phosphate (18-46-0)	0 (fall)	0 (fall)
Other fertilizers	15	30
Corn (fertilizer banded with the seed)		
All soils		
Urea (46-0-0)	0	0
Di-ammonium phosphate (18-46-0)	0	0
Other fertilizers — 100-cm rows		7
— 75-cm rows		10
— 50-cm rows		14
Sweet corn can be more sensitive to fertilizer placed with the seed. Do not apply fertilizer with the seed of super sweet hybrid sweet corn.		
Corn (fertilizer banded 5 cm to the side and 5 cm below the seed)		
All soils		
Urea (46-0-0)	40	60
Other fertilizers	55	90
At higher rates, band at least 15 cm from seed. At row widths other than 100 cm, the rate may be adjusted to provide the same maximum concentration in the row (e.g., in 50-cm row, the safe rate = 100/50 x 55 = 110 N).		
Corn (fertilizer broadcast)		
Sands, sandy loam		
Urea (46-0-0)	200	250
Canola (fertilizer with the seed)		
Up to 20 kg/ha phosphate fertilizer may be drilled with the seed as superphosphate or mono-ammonium phosphate. Do not apply N (except as mono-ammonium phosphate) or K with the seed.		
Flax (no fertilizer with the seed)		
Rates recommended are normally safe when broadcast.		
Peas, beans and soybeans (no fertilizer with the seed)		
All soils, fertilizer banded 5 cm to the side and 5 cm below the seed	30	90
Fertilizers containing more than half as much N as P$_2$O$_5$ (e.g., 16-16-16) often contain urea. Fertilizers containing urea are not suitable for banding at seeding in many cases.		

Some growers use much higher rates of banded fertilizer than are listed here, with no apparent problem. Crops are able to tolerate much higher rates of fertilizer with adequate moisture, but it is impossible to predict before planting when adverse conditions for germination will occur. Keeping below the maximum safe rates is the surest way to ensure a good start for the crop.

Excess fertilizer can harm seedlings because of effects from ammonia and salt. These effects are related to fertilizer nitrogen (N) and potassium (K) content. Toxicity varies widely depending on soil texture, moisture conditions, crop, fertilizer source and placement. Table 9–21, *Maximum Safe Rates of Nutrients*, this page, provides guidelines that will most likely limit injury to less than 10% of the cases where they are used. Injurious effects include reduced or delayed germination or retarded growth. Weather, stress and other conditions that affect growth may increase the chances of injury.

Foliar Fertilizers

Micronutrients can be supplied to crops through foliar fertilization, particularly in instances where a deficiency is due to a tie-up of these nutrients in the soil (i.e., manganese). Quantities of nutrient that can be applied in this manner are limited because of the danger of leaf burning. Take care when combining nutrients that the resulting solution is not too concentrated. Check pesticide labels before mixing foliar nutrients with any pesticide spray.

Calculating Fertilizer Requirements

Calculate the mineral fertilizer required for optimum crop production by deducting the nutrients in manure and legumes from the total nutrients required. Further, it is often beneficial to separate the starter component of the fertilizer, which is generally high in phosphorus, from the balance of the nitrogen and potassium.

The choice of starter fertilizer will depend on the crop to be grown, the mineral fertilizer requirements and the equipment available. It is often equally efficient to apply part of the fertilizer as a starter and broadcast the rest, as it is to apply all the fertilizer through the planter or drill. The advantage to this program is savings in time and labour, and less risk of fertilizer injury to the seedling.

Deduct applications of starter fertilizer and side-dressed fertilizer from the total mineral fertilizer requirement. Broadcast any balance remaining. If only very small numbers remain, consider adjusting the rates of one of the other nutrient sources, ignoring the small residuals or planning a fertilizer application that will meet multi-year requirements (P & K only).

Field Scouting

10. Field Scouting

Field Scouting

Field scouting involves walking through a field and stopping at a number of locations to make observations. Regular field examinations help to accurately identify yield-limiting problems during the growing season when they can often be corrected so that full yield potential can be preserved. Every cropping season should begin with the recording of vital field information (soil fertility and crop inputs) on a field record form. Example field record forms are available on the OMAFRA website at www.ontario.ca/crops. This information, combined with regular field scouting, accurate identification and diagnosis of problems and a record of those observations, makes for a successful crop monitoring program. In addition to dealing with immediate issues, record scouting information for future reference to avoid problems in subsequent years. For example, a pest such as soybean cyst nematode impacts both crop rotation and variety selection when soybeans are grown again in the same field. Accurate records will aid in the decisions required to help manage this pest.

Timing of Field Scouting Operations

Early recognition of pests and their control will minimize their economic impact on a crop. Under each commodity chapter within this publication, crop scouting calendars illustrate the timing associated with the common crop pests found in Ontario. It is important to monitor fields consistently and frequently since pest dynamics can change rapidly throughout the season. As optimum plant populations are critical for achieving good yields, evaluate crop stands within 1–2 weeks of plant emergence. Early in the growing season, scout weekly. When approaching a control threshold, such as the application of a post-emergent herbicide or a fungicide, fields may require scouting daily. Later in the season, bi-weekly scouting is normally sufficient. Keep in mind that some insects and diseases occur later in the season and may approach control thresholds in a matter of days. Examples of such pests include armyworm, soybean aphids and stalk rots. If field and weather conditions favour these later-season pests, scouting should continue weekly.

Scouting Tools and Techniques

Tools used to monitor crop development and pests vary with the crop and the pest. Basic field scouting equipment includes:

- a clipboard with field scouting forms or field pocket guide to record observations
- field maps
- a shovel
- a pocketknife
- plastic and paper bags for collecting specimens
- a 10X hand lens and a sampling frame (i.e., hula hoop)

Professional scouts often carry other tools that could include aerial field images, a camera, labels for identification, reference guides, a sweep net, vials and isopropyl alcohol, sticky cards or traps to detect insect pests, a GPS unit to mark the location, flagging material, etc. It is also wise to wear appropriate clothing for protection from the sun and from unknown risks such as poisonous plants and mosquitoes. Be aware of recent pesticide treatments applied to the field and obey re-entry intervals indicated on product labels.

When scouting for insects that move too quickly in the canopy to be spotted at a glance, it is sometimes easier to use the drop cloth or sweep net. A drop cloth can be spread on the ground between two rows of crop. The crop can then be pulled over the cloth and shaken vigorously so that any insects on the plant are dislodged onto the cloth. The insects can then be identified and counted.

Using Sweep Nets

A sweep net is the preferred scouting method when evaluating a solid stand crop such as alfalfa, canola or solid seeded soybeans. Standard 37-cm (15-in.) diameter sweep nets are available commercially through the various companies listed in Appendix A, *Insect-Monitoring Equipment Supply Companies*, on page 257. While walking through the canopy, swing the net from side to side in a pendulum-like motion, across the top of the canopy so that the top of the net is sweeping across the top 37 cm (15 in.) of the canopy. Avoid collecting soil in the net by not digging into the ground during the sweeping procedure.

There is some confusion as to what is considered a single "sweep" in many of the thresholds established in pest management. Some researchers set thresholds based on the definition of one sweep consisting of two 180° arcs bringing the net across from one side of the body to the other and back to home while walking slowly forward. Other researchers established thresholds based on one sweep consisting of only one 180° arc bringing the sweep net only from one side of the body to the other, once, (which is exactly half of what the others considered a sweep). It is therefore important to determine which definition of a sweep has been used for each threshold recommendation, before determining pest populations in a field.

Table 10–1. Number of Recommended Sampling Locations Based on Field Size and Pest

Field Size		Number of Sampling Locations	
(hectares)	**(acres)**	**Insects/Diseases**	**Weeds**
Up to 8	Up to 20	5	10
8 to 12	20 to 30	8	15
12 to 16	30 to 40	10	15

If the incorrect definition of a sweep for a threshold is used, over- or underestimation of the average number of insects per sweep can occur. In this publication, the definition of a sweep (i.e., either a 180° arc or two 180° arcs) is defined for each threshold if it is known.

After completing the indicated number of sweeps, quickly close the top of the net by grasping it just below the ring. Slowly open the net, remove any plant debris collected, identify and count the insects that have been captured. Repeat this in five areas (or the number identified in the threshold) of the field to get a good assessment of population levels across the field. Though sweep nets will not give an absolute number, they will provide a relative estimate of insect pressures, allowing for a quick assessment of the presence of a particular insect.

Number of Sampling Locations

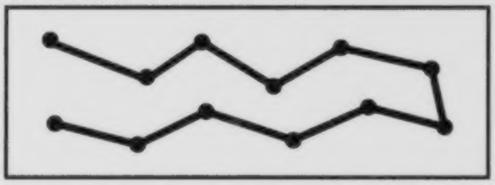
The number of sampling locations in a field depends on factors such as field size, crop, pest type and stage of development, level of infestation, timing, etc. The general number of sampling locations for a range of field sizes is suggested in Table 10–1, *Number of Recommended Sampling Locations Based on Field Size and Pest*, this page. For scouting purposes, fields larger than 16 ha (40 acres) should be split into units of 16 ha (40 acres) or less.

Scouting Pattern

The scouting pattern should cover all parts of the field and observation locations should vary each time the field is scouted. However, when hot spots are identified, recheck them to monitor the development of the pest.

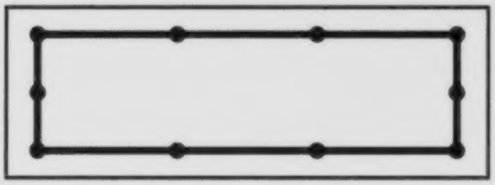
There are a few factors to consider when determining what scouting pattern to follow in your field:

- Use a scouting pattern that includes changes in variety/hybrid, soil type, past cropping history, fertilizer/manure application and any other factors that can affect plant growth. The pattern should cover all parts of the field and should vary each time the field is scouted. See Figure 10–1, *Scouting Patterns*, this page.
- Select sampling locations on the basis of a predetermined random pattern, as opposed to factors such as crop appearance, etc.



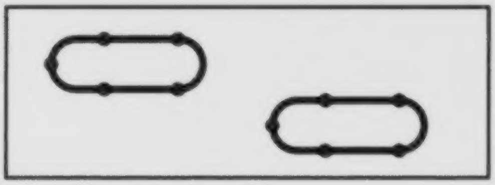
For Pests Uniformly Distributed Across the Field

- Randomly select sampling locations evenly across the field as shown above. This pattern is also appropriate for soil sampling.
- Pests that fit this scouting pattern include corn rootworm, European corn borer and stalk rots.



For Pests Expected in Headlands or Outside Rows

- Randomly select sampling locations evenly around the edges of the field, as shown above.
- Pests and problems that fit this scouting pattern include armyworm, spider mites and soil compaction.



For Pests Developing in Specific Areas of the Field

- Concentrate sampling locations in areas where the problem or pests are most likely to be found, as shown above, but also monitor other areas of affected fields.
- Pests that fit this scouting pattern include phytophthora root rot in damp clay soils and black cutworms in weedy patches.

Figure 10–1. Scouting Patterns

- Start scouting at least 20 m (66 ft) into a field. Avoid outside rows and headlands in the scouting pattern unless there are specific reasons for sampling these areas (e.g., armyworm moving from cereal into corn fields).

Plant Population and Pest Infestation Levels

Plant population and some pest infestation levels are determined by making counts in areas of a given size and then multiplying that number by a factor to obtain the population per acre.

Table 10–2. Plant Populations at Various Row Widths

Row Width		Length of Row Equal to 1/1,000 acre[1,2]	
centimetres	inches	metres	feet
38	15	10.6	34 ft. 10 in.
51	20	8.0	26 ft. 1 in.
56	22	7.3	23 ft. 10 in.
71	28	5.7	18 ft. 8 in.
76	30	5.3	17 ft. 5 in.
81	32	5.0	16 ft. 4 in.
86	34	4.7	15 ft. 5 in.
91	36	4.4	14 ft. 6 in.
97	38	4.2	13 ft. 9 in.

[1] To obtain the number of plants per one-thousandth hectare, multiply the number of plants in the length of row by 2.47.

[2] Multiply the number of plants counted in the length of row above by 1,000 to determine the number of plants/acre.

For row crops, plant population can be calculated by counting the number of plants in a thousandth of an acre (1/1000), then multiplying the count by 1,000 to obtain the number of plants per acre. See Table 10–2, *Plant Populations at Various Row Widths*, this page.

To determine plant population in narrow-row crops or weed/insect infestation levels, a sampling frame with a known area can be placed on the ground. Count all pests or weeds within the area of the frame. This can be accomplished using a square frame (e.g., 50 cm x 50 cm = 0.25 m^2) or a circular frame (e.g., a hula hoop). The "hula" hoop method is presented in Table 10–3, *Hula Hoop Method for Determining Plant and Pest Populations*, this page.

Many insect action thresholds are expressed as the average number of insects per plant, per sweep, per square metre or per foot of row. Some may also be based on a percentage of defoliation or damage. Regardless of the method used, take at least 10 random counts in each field to determine average populations. Record each count and then take the average of all counts as the estimate of the field pest population.

Recording Field Observations

Field scouting records are an essential tool for making current and future management decisions. Using a field scouting form will facilitate and standardize the recording of field observations. Once recorded, add the scouting data to the field record files. Computer software is also available to record and manipulate data from field observations.

Table 10–3. Hula Hoop Method for Determining Plant and Pest Populations

Inside Diameter of Hoop in Centimetres (inches)	Area in Metre^2 (ft^2)	Factor by Which to Multiply the Number of Plants Within the Hoop to Equal:	
		Plants per Hectare	Plants per Acre
91 (36)	0.65 (7.0)	15,385	6,165
84 (33)	0.55 (6.0)	18,182	7,334
76 (30)	0.45 (4.9)	22,222	8,874
69 (27)	0.37 (4.0)	27,027	10,956
61 (24)	0.29 (3.2)	34,483	13,865
Inside dimensions of a square frame in centimetres (in.)			
50 x 50 (20 x 20)	0.25 (2.7)	40,000	16,133
100 x 100 (40 x40)	1.00 (11.1)	10,000	3,924

Count the number of plants that are found within the hoop or square and multiply that number by the pre-determined factor listed above to determine plant population per hectare or acre.

Information to be recorded during scouting events includes:

- field name/code, location and scouting date
- growth stage and condition of the crop
- hybrid/variety planted and whether it's resistant or transgenic
- flowering, tasselling, heading dates
- weather conditions
- soil conditions
- weed species present, growth stage, location and population (including any natural enemies present)
- diseases present, growth stage, location and population
- insects present, growth stage, location and population
- crop damage
- field map
- results of scouting procedures performed
- action required

Note: The growth stages and populations of each weed or pest species should be identified separately.

Sample Handling and Submission

It can be difficult to identify a pest or field problem. Seek diagnosis and assistance from other resources, including experts and/or diagnostic laboratories. For more information on how to take proper samples, where to obtain sample submission forms and diagnostic service fees, see Appendix I, *Diagnostic Services*, on page 266.

Using Growing Degree Days and Crop Heat Units

Growing Degree Days

Growing degree days (GDDs) are used to estimate the growth and development of plants and insects during the growing season. Insect and plant development are very dependent on temperature and the daily accumulation of heat. The amount of heat required to move a plant or pest to the next development stage remains constant from year to year. However, the actual amount of time (days) can vary considerably from year to year because of weather conditions.

Each organism has a minimum base temperature or threshold below which development does not occur. These base temperatures have been determined experimentally and are different for each organism. GDD information can be very useful for predicting crop and insect development. Some Ontario crops still use the GDD system while others have moved to the crop heat unit (CHU) system described in the next section. Field crops that still use the GDD system are cereals (Base: 0), alfalfa (Base: 5) and canola (Base: 5).

To calculate GDD, first determine the mean temperature for the day. This is usually done by taking the maximum and minimum temperatures for the day, adding them together and dividing by 2. The base temperature is then subtracted from the mean temperature to give a daily GDD. If the daily GDD calculates to a negative number it is made equal to zero. Each daily GDD is then added up (accumulated) over the growing season.

Growing degree days are sometimes referred to as "degree days" or the "degree days averaging method." Some jurisdictions also use the term "heat units" interchangeably with "degree days." In Ontario, the terms "growing degree days" (GDD) and "crop heat units" (CHUs) are used independently since they represent two very different, temperature-dependent, development models.

Growing Degree Day Equation

The GDD equation used by OMAFRA is calculated as follows:

$$\text{Daily GDD} = \left(\frac{T\ max - T\ min}{2}\right) - T\ base$$

T max = the daily maximum air temperature
T min = the daily minimum air temperature
Tbase = the GDD base temperature for the organism being monitored

Example

Maximum Temperature: 28°C
Minimum Temperature: 15°C

Pest: European corn borer (ECB)
Base Temperature for ECB: 10°C

Calculation

$$\text{Daily GDD} = \left(\frac{28 - 15}{2}\right) - 10 = 11.5$$

Therefore: 11.5 growing degree days were accumulated for that day for the European corn borer GDD model.

There are four factors to consider when comparing GDD accumulations from various sources or regions.

1. **Are the base temperatures used in the equations the same?**
   Different organisms have different base temperatures used to calculate GDDs: 150 GDD at base 10 does not equal 150 GDD at base 0.

2. **Are the start dates for the accumulations the same?**
   Generally, GDD accumulations start on April 1 each year, but some insect GDD models start at the emergence of a specific life stage. This is referred to as a biofix.

3. **Are the equations used to calculate the daily GDD the same?**
   Many modifications to the simple GDD calculation have been developed over the years and may be referred to generally as degree days.

4. **Are the temperatures used in degrees Celsius or Fahrenheit?**
   GDD accumulations will vary significantly, depending on whether they are being tracked in Celsius or Fahrenheit. GDD models have been designed specifically for use in one or the other and cannot be interchanged without making conversions. The ECB GDD model was based on measurements in Celsius.

Table 10–4. Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures

		Daily CHU Values for °C Temperature Recordings																				
		Daily Recorded Minimum Temperature																				
	(°C)	<5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Daily Recorded Maximum Temperature	< 10	0	1	1	2	3	4	5	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	11	2	2	3	4	5	6	7	8	:	:	:	:	:	:	:	:	:	:	:	:	:
	12	3	4	5	5	6	7	8	9	10	:	:	:	:	:	:	:	:	:	:	:	:
	13	5	5	6	7	8	9	10	11	11	12	:	:	:	:	:	:	:	:	:	:	:
	14	6	6	7	8	9	10	11	12	13	14	15	:	:	:	:	:	:	:	:	:	:
	15	7	8	9	10	10	11	12	13	14	15	16	17	:	:	:	:	:	:	:	:	:
	16	8	9	10	11	12	13	13	14	15	16	17	18	19	:	:	:	:	:	:	:	:
	17	10	10	11	12	13	14	15	16	16	17	18	19	20	21	:	:	:	:	:	:	:
	18	11	11	12	13	14	15	16	17	17	18	19	20	21	22	23	:	:	:	:	:	:
	19	12	12	13	14	15	16	17	17	18	19	20	21	22	23	24	25	:	:	:	:	:
	20	12	13	14	15	16	17	17	18	19	20	21	22	23	24	25	26	26	:	:	:	:
	21	13	14	15	16	16	17	18	19	20	21	22	23	24	25	25	26	27	28	:	:	:
	22	14	14	15	16	17	18	19	20	21	22	23	23	24	25	26	27	28	29	30	:	:
	23	15	15	16	17	18	19	20	20	21	22	23	24	25	26	27	28	29	29	30	31	:
	24	15	16	16	17	18	19	20	21	22	23	24	25	25	26	27	28	29	30	31	32	33
	25	16	16	17	18	19	20	21	21	22	23	24	25	26	27	28	29	30	30	31	32	33
	26	16	16	17	18	19	20	21	22	23	24	24	25	26	27	28	29	30	31	32	33	33
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	31	16	17	18	19	20	21	21	22	23	24	25	26	27	28	29	30	30	31	32	33	34
	32	16	17	18	19	20	20	21	22	23	24	25	26	27	28	29	29	30	31	32	33	34
	33	16	17	17	18	19	20	21	22	23	24	25	26	26	27	28	29	30	31	32	33	34
	34	16	16	17	18	19	20	21	22	23	23	24	25	26	27	28	29	30	31	32	32	33

Crop Heat Units (CHUs)

Crop heat units are based on a similar principle to growing degree days. CHUs are calculated on a daily basis, using the maximum and minimum temperatures; however, the equation that is used is quite different. The CHU model uses separate calculations for maximum and minimum temperatures. The maximum or daytime relationship uses 10°C as the base temperature and 30°C as the ceiling, because warm-season crops do not develop at all when daytime temperatures fall below 10°C, and develop fastest at about 30°C. The minimum or nighttime relationship uses 4.4°C as the base temperature and does not specify an optimum temperature, because nighttime minimum temperatures very seldom exceed 25°C in Ontario. The nighttime relationship is considered a linear relationship, while the daytime relationship is considered non-linear because crop development peaks at 30°C and begins to decline at higher temperatures. Daily crop heat units are calculated by using the average of the two daily values from the equations below or can be read from the matrix in Table 10–4, *Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures*, this page. Figure 1–1, *Crop Heat Units (CHU-M1) Available for Corn Production*, on page 9, gives a map view of season total CHU(M1) accumulations for Ontario.

Producers who record high and low temperatures can use Table 10–4, *Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures*, previous page, to calculate CHUs for their own farm. As of 2009, CHUs accumulate from May 1st at all locations and end with the first occurrence of −2°C in the fall. Corn development is driven primarily by temperature, and this is especially true during the planting-to-silking period. Unlike soybeans, day length has little effect on the rate at which corn develops. The Ontario Crop Heat Unit System has been developed to calculate the impact of temperature on corn development.

Calculating Daily CHU

The following equation is used to calculate a daily CHU for a site:

$$\text{Daily CHU} = \left(\frac{Y\ \text{max} + Y\ \text{min}}{2}\right) \text{ where:}$$

Y max
$= (3.33 \times (T\ \text{max} - 10)) - (0.084 \times (T\ \text{max} - 10.0)^2)$
(If values are negative, set to 0)

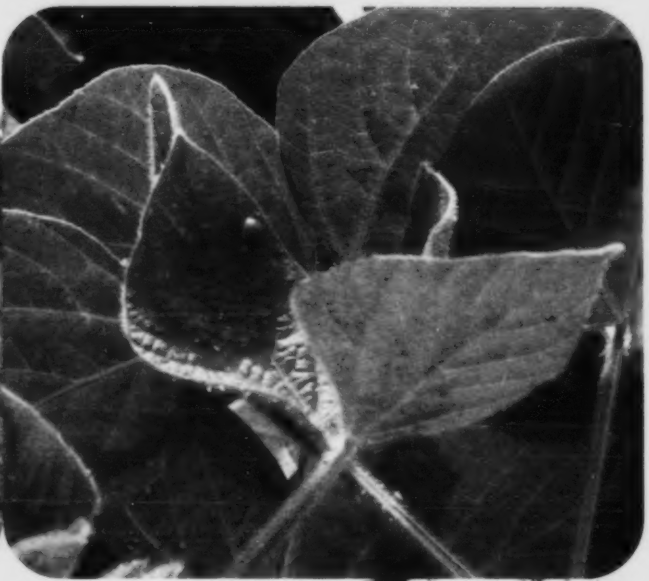
Tmax
= Daily maximum air temperature (°C) (measured from midnight to midnight)
(Accuracy should be <0.25°C)

Y min
$= (1.8 \times (T\ \text{min} - 4.4))$
(If values are negative, set to 0)

Tmin
= Daily minimum temperature (°C)

Field Record Forms

There are many methods of recording field data, ranging from paper to electronic. Examples of various forms can be found on the OMAFRA website at www.ontario.ca/crops or on the OSCIA website at www.ontariosoilcrop.org.



On-Farm Stored
Grain Management

11. On-Farm Stored Grain Management

Maintaining stored grain in good condition requires careful, routine inspection and good storage practices. Good storage practices consist of more than simply putting good-quality grain into a weatherproof container.

Storing Grain in Bins

When grain is loaded into storage it is at its peak quality. Over time, the quality of the grain will only decrease; it seldom, if ever, improves. The following strategies will help maintain the quality of your grain at the same level as when it went into the bin.

Good Bin Management Suggestions

- Treat empty bins to control any stored grain pests that may be living in cracks, crevices and below the aeration floor.
- Clean any grain going into a bin.
- Remove fines and other foreign material to reduce air flow restrictions and possibly reduce the risk of spoilage.
- Core a bin (augur out some grain) after filling to establish the flow funnel and redistribute the fines, even if the removed material is put back into the same bin.
- Install a manometer in the air plenum below the aeration floor to monitor the static pressure of the air moved by the fan. For information on how to build a manometer, see Figure 11–1, *Home-Built Manometer*, this page.
- Use the measured static pressure and the fan performance curve to determine the air flow delivered by the fan.
- Tightly cover unused aeration fan inlets to prevent unintentional air movement through the grain.

Why Aerate Grain in Bins

Grain bin aeration:

- removes field heat at the time of harvest or cools grain from a dryer
- brings the whole mass to a uniform temperature
- removes moisture that has respired from the stored grain as a result of temperature changes caused by the outside air

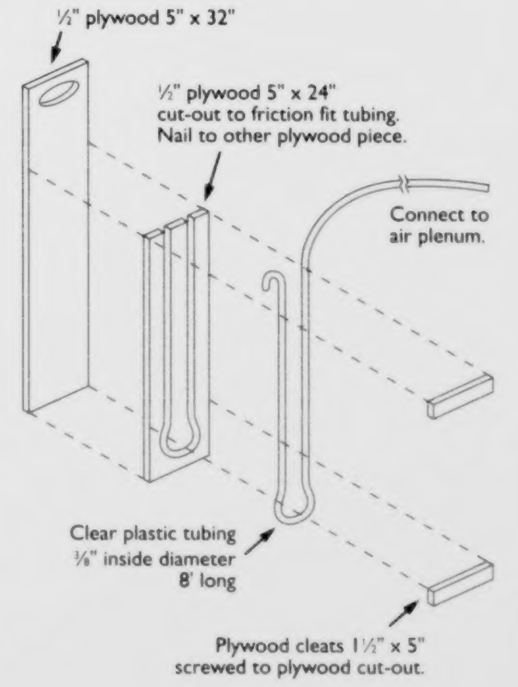


Figure 11–1. Home-Built Manometer
A manometer is a simple device that uses a fluid column to measure static pressure. It can be used to measure the static pressure in the air plenum between the perforated floor and the concrete pad under a grain bin.

As bin surfaces are warmed or cooled by the sun or outside air, air currents start to move by convection in the grain mass. Moisture from the grain is carried by these convective air cells and condenses on colder surfaces. These colder areas may be inner bin surfaces or the grain itself. Spoilage can occur if this convective air movement is not arrested. Routine aeration of the bin contents will prevent convective air movement.

Maintain a temperature differential of no more than 5°C between the grain mass and the average outside air temperature to prevent convective air movement from occurring.

Table 11–1. Time Required for Aeration Front to Move Through Grain

Airflow Rate (CFM/bu)	Grain Cooling (hr)		
	Fall	Winter	Spring
1/20	300	400	240
1/10	150	200	120
1/5	75	100	60
1/4	60	80	48
1/3	45	61	36
1/2	30	40	24
3/4	20	27	16
1	15	20	12

CFM = cubic feet/minute; 1 CFM/bu = 13 L/sec/m^3

Basics of Aeration

- Bring the whole grain mass to the same temperature.
- Operate the fan only when relative humidity levels will not add moisture to the grain.
- Operate the fan for long enough to totally change the whole grain mass temperature — this may require a number of days. The time required for this will depend on the airflow rate per bushel.
- Become familiar with Equilibrium Moisture Content charts for the grain or beans you are storing (see the section *Harvest and Storage* in each commodity chapter). Run the fan only under outside conditions that will not add moisture to the stored product. Relative humidity levels of night-time air can add moisture to small grains, beans and natural air dried corn.
- See Table 11–1, *Time Required for Aeration Front to Move Through Grain*, this page, for the aeration time required to completely change the bin content temperature.

Grain Storage Monitoring

Monitor all bins of grain stored on the farm on a routine schedule.

Stored grain that is used regularly for feed can be monitored as it is being used. Set up a routine for checking the bins of grains that are not being used regularly. Grain can go out of condition quickly. By carefully and diligently monitoring storage bins, growers will be able to detect the warning signs of possible spoilage problems and be able to take appropriate action to prevent further reductions in quality.

Monthly Bin Monitoring Checklist

- Turn on the aeration fan.
- Climb up and look inside the bin. Look for signs of moisture on the underside of the roof. If water droplets or ice are present, aerate the bin. Moisture from the grain has been carried into the attic space and condensed on the roof metal.
- Run the aeration fan if a light dusting of snow has been driven into the top of a storage bin. It will sublimate and be discharged as harmless water vapour. If much greater amounts of snow are found, shovel it out.
- Check for any off-odours. The air should smell like clean grain.
- Check the grain surface to see if it looks the same as the last time. If it looks dull or off-colour, investigate further.
- Check for changes in the static pressure or the working pressure of the fan in the plenum under the aeration floor since the previous month. A decrease is no cause for concern. An increase, however, indicates that something has increased the resistance of the air as it moves through the grain mass. Investigate deeper into the grain mass.
- Look for any signs of insect activity.
- Record your notes in a monitoring logbook for comparison with the next month's readings.

Insect Management for Farm-Stored Grain

The key to controlling insects in stored grain is good sanitation and storage practices.

The following strategies are essential for preventing infestations, reducing the need for rescue fumigation treatments.

Keep a Sanitary Facility

The most important strategy is to keep the facility insect free by cleaning bins and equipment before storing grain. Grain residues from previous crops are the main source of new infestations. At least 2 weeks before filling bins, ensure the facility is thoroughly cleaned and pest free by removing all grain residue, as well as caked material, using a good vacuum cleaner. Ensure that all old grain has been removed from cracks and crevices, behind partitions, between double walls, outside and under bins, in grain-handling equipment, inside aeration piping and under perforated floors. Harvesting and grain handling equipment containing old crop residues are a very important source of new infestations. Fully perforated floors present a problem because they cannot be easily lifted for cleaning, and grain dust will accumulate and may become infested with grain storage pests.

Clean up all spills of grain and feed around handling and storage facilities. Burn all grain that is removed, deposit it in a sanitary fill or grind it up for feed. Leave space between feed rooms and storage facilities, because feed rooms are difficult to keep free of pests. Once established, storage pests can quickly spread to nearby storage facilities.

Do not store grain in buildings that shelter animals or hay. Mangers, feed boxes and troughs are often infested with insects. These shelters are also warmer and provide an excellent wintering site for insects.

Maintain Sound Storage Facilities

After clean-up, repair facilities so that they are pest-proof. Seal cracks and crevices that may allow insects to enter.

Store Clean, Dry Grain

Never store new grain with old grain, because insects will spread from the old grain to the new. Ensure that grain being placed in the storage facility is pest-free. Moulds as well as insects are much more troublesome in moist grain. If stored grain has more than 15% moisture, check it regularly. Wheat should be dried down to 12% moisture if you are planning to store it for longer than a month through the warm summer months. Corn should be dried to 14% moisture.

Monitor Storage Temperature and Sample for Insects

Wheat is the crop most susceptible to infestations because it is harvested during the summer when insects are most active inside and outside the storage facilities. Once in the bin, the grain is still warm and can provide an excellent habitat for stored-grain insects. In Ontario, corn storage usually follows wheat storage, and infestations can easily be carried from the wheat to the corn. Monitor the temperature of the grain using temperature sensors placed throughout the grain pile. Warm areas in the pile often indicate insect and/or spoilage problems.

Using aeration to cool down grain in the fall will reduce insect infestation and slow reproduction. Insects do not develop in grain with temperatures below 10°C and can be killed if temperatures are kept below –10°C for over 10 days. Rusty grain beetle and Indian meal moth can be monitored using plastic probe traps Plate 34 on page 284). These probe traps are very sensitive and will show an infestation well before it reaches the economic threshold. If rusty grain beetle or Indian meal moths are found, fumigate the grain.

Treat Empty Bins With Diatomaceous Earth

Diatomaceous earth is a non-toxic dust made from a silicone-dioxide mixture from prehistoric, marine diatoms. When in contact with insects, the diatomaceous earth absorbs the protective waxy coating on the insect, causing it to die from dehydration. Apply the product to the empty bin through aeration fans at least 2 weeks prior to grain storage. Apply it to the grain as well, as it is being augured into the bin or storage facility. Wear a protective mask when applying diatomaceous earth to avoid inhaling the dust. See OMAFRA Publication 812, *Field Crop Protection Guide*, for detailed application and label information.

Do not exceed application rates when treating grain, as this will result in auger plugging problems.

Preventative insecticides are not a substitute for good storage sanitation practices.

If bin surfaces are dusty or covered with caked material, control products may not penetrate to kill crawling insects. Malathion is no longer recommended for Indian meal moth control as this insect has acquired resistance and is frequently not controlled by this product.

Use Rescue Treatments When Necessary

Should an insect problem occur, fumigation might be necessary. Turning the grain may reduce a secondary pest problem to below economic damage. However, if rusty grain beetles or Indian meal moths are evident, the problem is serious. If webbing is found on the surface of the pile, rake and remove this layer before fumigating. For information on fumigants, see OMAFRA Publication 812, *Field Crop Protection Guide*. Grain must be above freezing temperatures for all fumigants to work properly. Because of this fact, fumigation may not always be possible when desired. Fumigants may only be applied by a licensed exterminator. Remove livestock and poultry that are in the same building, especially if they are under the grain bin.

Identify Pests Properly

Stored-grain insects are not specific to one crop but can move and feed across commodities. It is important to know which insect pest you have in your facility. Proper identification and pest density assessment are important, because management strategies may differ, depending on the pest. Proper identification will also help determine the source of infestation. Some insects are only incidental pests and may not cause economic loss.

Stored-Grain Insects

Scouting Technique for Stored-Grain Insects

In the grain pile, place four plastic probe traps (see Plate 34 on page 284) halfway between the centre and edge of the bin, in an X pattern, with the centre of the bin as the centre point of the X. Place the traps vertically into the grain so that the top of the probe traps are about 25 cm (10 in.) below the grain surface. Retrieve and examine them at least once a week. Under high infestation levels, insects may be trapped in a day or two. These probe traps are very sensitive and will show an infestation well before it is economically threatening. If insects are present in probes, follow the management strategies listed in Table 11–2, *Insect Management Strategies for Farm-Stored Grain*, this page. Insecticide and fumigant recommendations can be found in Publication 812, *Field Crop Protection Guide.*

Table 11–2. Insect Management Strategies for Farm-Stored Grain

Description	Life History	Damage	Management Strategies
Rusty Grain Beetle (Plate 35 on page 284)			
• flat, reddish-brown beetle • approx. 2 mm (1/16 in.) long • antennae are as long or longer than its head and thorax combined • flies when temperatures are above 25°C • larvae are white, approx. 3 mm (1/8 in.) long, have two brown projections at the rear • moves easily through the whole grain pile because of its small size	• cold-tolerant • overwinters as an adult • lays up to 500 eggs on surface of kernels • larvae hatch in 35 days • larvae penetrate seed and pupate inside • adults emerge, leaving distinctive exit hole	• adult and larvae feed on germ and bran • feeds on cracked or sound grain • feeds throughout pile of grain • high infestations generate heat, causing grain to mould and spoil	• proper sanitation and monitoring practices • treatment with diatomaceous earth to protect from re-infestation • See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information.
Indian Meal Moth (Plate 36 on page 284)			
• **adult** approx. 12 mm (1/2 in.) long • "A-shaped" when wings are at rest • wings are grey, bottom half are bronzy • active in the evening • **larvae** grow to approx. 8 mm (3/8 in.) long • larvae range from pinkish-cream to pale yellow to pale green/yellow with black heads • larvae have three pairs of legs on thorax, five pairs of abdominal prolegs • mature larvae wander, looking for places to pupate	• can go through its entire life cycle in approximately 21–30 days under warm conditions • not cold-tolerant • temperature limits number of generations per year • females lay eggs on kernels of grain on pile surface • young larvae found in grain clumps (3–10 kernels) held together by silk	• adults do not feed or cause damage • larvae feed on germ and bran, leaving kernels with these missing • all stages of larvae spin webbing (increases as preparing to pupate) • typically stays on top of pile, no more than 50 cm (20 in.) deep • high populations result in a mat of grain with silks up to 50 cm (20 in.) deep	• moth is resistant to malathion • remove webbed layer of grain before fumigation • See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information.
Granary Weevil (Plate 37 on page 285)			
• **adult** is a dark-brown snout beetle • approx. 4 mm (3/16 in.) long • **larvae** are white, wrinkled and wingless, 4 mm (3/16 in.) long • larvae always found inside grain, only leave kernel as adults • only attacks cereal grains, not legumes • cannot fly • can be confused with rice weevil: on surface of thorax, the small pits are round rather than oval • cannot survive cold	• female lays eggs into holes in the grain created with her snout • cements holes shut • larvae develop inside grain • adults live up to 8 months	• adult and larvae feed on sound grain • larvae spend entire life in one kernel, feeding on endosperm • several larvae can be inside one kernel • leaves round exit holes when exits kernel as adult	• See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information

Table 11–2. Insect Management Strategies for Farm-Stored Grain

Description	Life History	Damage	Management Strategies
Pea/Bean Weevils			
• two species that attack peas or beans • damage and larvae resemble that of granary weevil • **adults** are short and squat (34 mm or 1/8–3/16 in.) • heads are tapered at front • usually tan coloured with faint longitudinal striping • **larvae** are creamy, yellow, legless and have a brass-coloured head capsule		• pea weevils attack peas, bean weevils attack beans • adults lay eggs in maturing beans in field with no apparent visible damage • damage noticed when new adults emerge from seeds, leaving round holes	• monitor beans for damage in storage • react with a fumigation • sort beans visually to remove "picks" • heavily infested peas or beans can be fed to livestock • See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information.
Lesser Grain Borer (Plate 38 on page 285)			
• **adult** is a brown-to-black beetle • approximately 2 mm (1/16 in.) long • cylindrical in shape • small numerous pits on surface of wings • adult identified by location of head • head is turned downward and covered by large hood (prothorax) • larvae are creamy-white, C-shaped, with a dark head tucked into the thorax • musty odour associated with this pest	• female borer lays eggs in cluster on surface of kernels • larvae hatch and bore into the kernel • completes development inside kernel	• pest may move into Ontario due to climate warming • adult and larvae cause damage to sound grain • bore irregularly shaped holes into the grain • leave only shell and powdery dust • adult and larvae enter and exit several grain kernels • several individuals may attack same kernel • also feed off grain dust	• advise provincial field crop entomologist if found • See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information.
Grain Lice			
• also known as psocids or book lice • **adults** are soft bodied • approximately 1–2 mm (1/32–1/16 in.) long • have large heads with long antennae • range from brown to white and often are opaque • can be winged or wingless • resemble aphids • **young** are smaller and slightly paler than adults	• incomplete metamorphosis (young nymphs resemble adults) • several generations • can multiply quickly under warm conditions	• not a direct pest of grain • secondary pest that feeds on grain dust and damaged kernels • can be seen running over pile when numerous; visually inspect grain surface for tiny, fast-moving insects • generally restricted to the top of the grain pile	• turning and cleaning the grain reduces populations • lice are found in damp conditions • lowering humidity lowers populations • See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information.
Mites			
• **adults** barely visible to the naked eye • approximately 0.5 mm (1/64 in.) long • rounded • eight-legged • yellowish-brown • **larvae** look like adults but have six legs • two nymphal stages look similar to adult with four pairs of legs		• incidental insect on grain going out of condition • prefers damp grain • feeds on grain dusts and moulds	• keep grain dry and in good condition • See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information.

12. Weed Control

Crop Yield Losses Due to Weeds

Yield losses due to weed competition will be greatest when:

- weeds emerge with or prior to crop emergence
- weeds are at high densities
- broadleaf weeds are present since they are more competitive than grasses
- there is limited soil moisture

Weed control is an important part of crop production. In general, agronomic practices that produce a healthy, fast-growing crop will provide the best competition against weeds. Consider cultivation, rotation and other effective cultural practices for weed control along with herbicide treatments, when developing a weed control program. Any single method of weed control or the continuous use of the same herbicide program will lead to the build-up of weeds resistant or tolerant to that control method.

An integrated approach to weed management that uses all available weed control strategies to manage weed populations can reduce herbicide use and optimize economic returns.

Integrated weed management strategies include:

- **Field scouting** to determine the weed species present, as well as density and population of weeds. Additional field scouting following application of control measures also helps to evaluate the effectiveness of the weed management programs used.

- **Crop rotations** — effective in reducing weeds, especially perennials that grow best in a particular crop. Rotating crops can allow for different herbicides or tillage practices to be used, which may be particularly effective on specific weed species. For example, forages are known to reduce the populations of annuals in the first year of the next crop, but annual weeds can be a problem when establishing forages.

- **Crop and variety/hybrid characteristics** — The early-season harvest of cereal crops creates an opportunity to improve weed control in the field during the late summer. Leaving weeds to grow following cereal harvest can result in a high weed seed return to the soil seed bank, creating weed problems in following crops. Do not leave weeds to grow following harvest when they can reach maturity and produce seed. Following cereal harvest, start control practices for annual weeds earlier than for perennial weeds, such as perennial sow thistle and field bindweed.

- **Cover crops** such as rye, red clover, buckwheat, oilseed radish, oat or over-wintering crops such as winter wheat or forages can suppress weed growth. When choosing a cover crop, consider how the cover crop and its management will affect the succeeding crop.

- **Fertilizers** (especially nitrogen) tend to stimulate the germination of some plant species and can affect the competition between crops and weeds in current and subsequent crops. Using banded phosphorus and potassium tends to concentrate the nutrients most where the crop has access to them. Side-dress nitrogen applications disturb the soil, which may stimulate the germination of weeds but also places nitrogen in a narrow band below the depth from which most weeds germinate and grow.

- **Population and row width** can affect weed growth. Narrow rows, high populations and fast-growing cultivars can have a competitive edge over weeds. Using vigorous, high-quality seed to achieve uniform stands at the recommended plant populations combined with early planting gives the crop a head start to compete with weeds. Deep planting can delay emergence and favour weed development but alternatively can be effective if a shallow tillage is utilized prior to crop emergence to remove the initial flush of emerging shallow-rooted annual weeds.

- **Tillage practices and mechanical weed control**
  - **No-till** — 75% of the weed seed bank is in the upper 5 cm (2 in.) of soil. The use of burndown herbicides has been effective for controlling many perennial weeds such as quackgrass or thistle.
  - **Moldboard plow** — the seed bank is more uniformly distributed over the depth of the plow layer.
  - **Blind harrowing** — kills small weed seedlings just before crop emergence.
  - **Rotary hoe** — at 10–20 km/hr, it has "fingers" that lift and mix soil, uprooting small weeds just before or shortly after crop emergence.
  - **Inter-row cultivation** — or scuffling, of row crops uproots small weeds and cuts off larger ones and smothers weeds in the crop row. Relative size of crops to weeds and timing of cultivation will determine success.
  - **Mowing** can help control weeds in crops such as newly established forages, cereal crops or cereal stubble

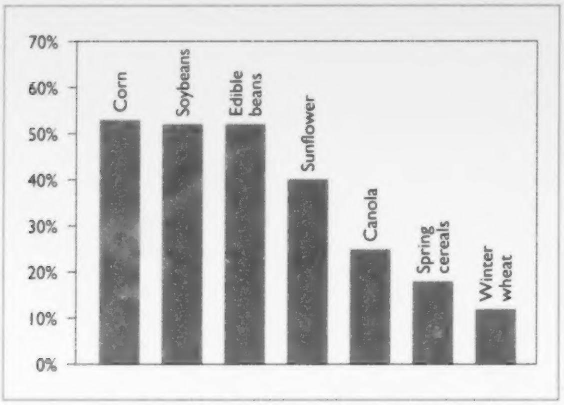


Figure 12–1. Typical Yield Losses of Different Field Crops Due to Weed Competition
Adapted from several sources (see below).*

- **Equipment practices** — Equipment can carry weed seeds from field to field. Combines, tillage equipment, wind and soil erosion, animals and birds can all transport weeds. Application of manure or other soil amendments can also lead to weed infestations. Proper sanitation and cleaning of equipment along with maintenance of field border areas all benefit long-term weed management in the field.

Additional information on these strategies can be found in the OMAFRA Publication 75, *Guide to Weed Control.*

Crop Competitiveness Against Weeds

Corn, soybeans, dry edible beans and flax are not strong competitors against weeds, so effective weed management during the critical period is needed to minimize yield losses. Canola, sunflowers, spring and winter cereals are stronger competitors against weeds, as is shown in Figure 12–1, *Typical Yield Losses of Different Field Crops Due to Weed Competition*, this page, however, weed removal during the early part of these crops development will minimize yield losses due to weeds.

* Figure 12–1, *Typical Yield Losses of Different Field Crops Due to Weed Competition*, is adapted from:

Weed Science Research Program, Department of Plant Agriculture – University of Guelph (1986–2008).

Wall & Smith, 2000. *Canadian Journal of Plant Science*, Vol. 80, No. 2, pp 411–47.

Milberg and Hallgren, 2004. *Field Crops Research*, Vol. 86, pp 199–209.

Martin et al., 2001. *Critical Period of Weed Control in Spring Canola*, Vol. 49, pp 325–33.

Varga et al., 2006. *Cereal Research Communications*, Vol. 34, No. 1, pp 701–04.

Table 12–1. Critical Weed-Free Periods for Common Ontario Field Crops

Crop	Critical Weed-Free Period	Source
Corn	3–10 corn leaf tips	Swanton (University of Guelph)
Soybean	1st–3rd trifoliate-leaf stage (V2–V3)	Swanton (University of Guelph)
Spring cereals	1–3-leaf stage (Zadok's 10–13)	Van Dam, Swanton (University of Guelph)
Winter wheat	500–1,000 Growing Degree Days (Base Temp. = 0)	Welsh et al., 1999 (University of Reading)
Forages	Year of establishment: 4–6 weeks after planting	Dillehay, Penn State University http://a-c-s.confex.com/crops/2007asa/techprogram/P30284.HTM
Canola	Emergence to 6-leaf stage	Van Acker (University of Guelph)

Critical Period for Weed Control in Field Crops

Yield loss caused by weeds can be reduced to less than 5% by maintaining good weed control during the critical period. Later-germinating weeds have a minimal impact on yields and have relatively low weed seed production.

The product label for postemergent herbicides indicates the growth stage of the weeds when optimum control can be obtained. Time weed control to optimize the critical period for the crop and the optimum growth stage of the weed.

The critical periods highlighted in Table 12–1, *Critical Weed-Free Periods for Common Ontario Field Crops*, this page, are a range. The critical point within the period will vary yearly and by site due to variations in climate, soil type, weed species and density. For example, the critical period will be earlier in the window for fields with light-textured soils under moisture stress conditions when weed densities are very high. Delaying control measures to the later part of the critical period in this situation would likely result in significant yield losses.

Impact of Soil Moisture on Weed Competitiveness

When soil moisture is abundant, the impact of weeds on crop yield loss is limited. Table 12–2, *Corn and Soybean Yield Losses From Weeds Under Adequate Soil Moisture vs. Inadequate Soil Moisture*, opposite page, compares observed yield losses due to weeds in corn and soybeans at the Elora Research Station in a season with more than adequate moisture compared to a "dry" season.

Table 12–2. Corn and Soybean Yield Losses From Weeds Under Adequate Soil Moisture vs. Inadequate Soil Moisture

Precipitation (mm – May to August)	Corn Yield Losses from Weeds (%)	Soybean Yield Losses from Weeds (%)
458	18	23
218	96	84

Source: Weed Science Research Program, Department of Plant Agriculture – University of Guelph (1986–2008).

Impact of Weed Species on Crop Yield Losses

Crop scouting determines the weed species present and their respective densities in the field. Some weeds are more competitive than others. Table 12–3, *Soybean and Corn Yield Losses Due to Weeds at Known Populations*, this page, shows the comparative yield losses caused by different weed species.

Consider weed competitiveness when deciding whether to treat escapes. The estimates in Table 12–3 are based on normal weather conditions and adequate soil moisture. They also assume that the weeds emerged with the crop. Yield losses may increase under drier soil conditions and may be variable under conditions of plant stress.

Also consider the effects of weed populations on crop quality and harvest procedures. For example, Eastern black nightshade is not a big threat to yield but can have a severe effect on crop quality of identity-preserved (IP) soybeans.

Mechanical Weed Control

Small annual weed seedlings can be partially controlled by blind harrowing prior to crop emergence. Use a set of light harrows operating at a shallow depth. Once the crop has emerged, a weeder-harrow (with L-shaped flexible tines) can be used until the crop is 5–10 cm (2–4 in.) tall. Timing of harrowing operations is critical to achieve success, since the weeds must be small and the soil surface dry and easily worked. Cultivation with the rotary hoe at high speeds (10 km/h) and at shallow (2.5–3 cm or 1–1.5 in.) depths when corn is 7–8 cm (3 in.) high or when beans are in the one-to-two leaf stage will help control small weed seedlings. These techniques will not reduce herbicide action and may in some years enhance chemical weed control. Under dry soil conditions, rotary hoeing dry edible beans 7–10 days following planting will help control emerging weeds but can also help activate soil-applied herbicides by mixing the chemical with moist soil. Rotary hoeing is unlikely to remove weeds that are past the two-true-leaf stage.

Table 12–3. Soybean and Corn Yield Losses Due to Weeds at Known Populations

Crop losses assume that the weeds have emerged with the crop.

	% Yield Loss	
Crop	**(1 plant/m^2)**	**(5 plants/m^2)**
Corn		
Annual Broadleaves		
Giant ragweed	13	36
Lamb's-quarters	12	35
Pigweed	11	34
Cocklebur	6	22
Ragweed	5	21
Wild mustard	5	18
Velvetleaf	4	15
Lady's thumb	3	13
Wild buckwheat	2	10
Eastern black nightshade	2	7
Annual Grasses		
Giant foxtail	2	10
Proso millet	2	10
Fall panicum	2	10
Barnyard grass	2	7
Green foxtail	2	7
Yellow foxtail	1	5
Old witch grass	1	5
Crabgrass	1	3
Soybeans		
Annual Broadleaves		
Cocklebur	15	41
Eastern black nightshade[1]	14	40
Giant ragweed	14	40
Lamb's-quarters	13	38
Pigweed	12	36
Ragweed	10	33
Velvetleaf	6	23
Wild mustard	5	20
Lady's thumb	4	15
Wild buckwheat	4	15
Annual Grasses		
Volunteer corn	4	15
Giant foxtail	3	12
Proso millet	3	12
Barnyard grass	3	12
Fall panicum	2	10
Green foxtail	2	8
Yellow foxtail	1	5
Old witch grass	1	4
Crabgrass	1	4

Adapted from www.wedpro75.com.

[1] Eastern black nightshade in soybeans reduces its quality.

Use inter-row cultivation to complement other weed control measures; it is most effective when weeds are small. Cultivate to a shallow depth to reduce germination of new weed seeds, soil moisture loss and corn root injury. Inter-row cultivation may be required when weeds escape a herbicide treatment. Consider weeds as escapes when they are 5–7 cm (2–3 in.) high. Since cultivation is less successful on larger weeds, cultivate quickly after determining a herbicide failure. If weeds are too large, consider alternative herbicide choices.

Band treatment of chemical over the row will reduce herbicide cost by half to two-thirds, depending on the row spacing and the width of the band. Control weeds between the bands with shallow inter-row cultivation. Consider the combination of the two operations when evaluating the economics of treating weeds in this manner.

Herbicide Resistance

There are over 18 herbicide-resistant weed species in Ontario affecting six different herbicide modes of action. Herbicide-resistant weed species will dominate a field's weed population when herbicides from a single chemical mode of action are used repeatedly. The speed at which herbicide-resistant weed populations are selected will depend on the complexity of the crop rotation and the herbicide modes of action repeatedly used. Applying the principles of integrated weed management will delay the onset of herbicide-resistant weed populations. To prevent or slow the development of resistant weeds, use the following approaches:

- identify, monitor and keep records
- rotate crops and herbicides
- prevent spread of weeds
- use alternatives to chemical weed control

For the latest on herbicide-resistant weed management and testing, see www.plant.uoguelph.ca/resistant-weeds.

Herbicide Injury

When the directions on a herbicide product label are followed correctly, the risk of injury to the target crop is very small. However, under less-than-favourable conditions, all herbicides have the potential to cause crop injury. The primary sources of herbicide injury to crops are:

- herbicide residues persisting from the previous crop year, especially in areas where spray overlaps occurred
- excessive product rate due to a miscalculation or spray overlap
- tank contamination due to fungicide or insecticide application that has herbicide residues in the spray solution when applied (e.g., a Folicur application on winter wheat that contains Ultim residues will cause considerable crop injury and yield loss).
- off-target drift from a herbicide application to a neighbouring crop
- herbicide applications made past the labelled crop stage. In cereals, late applications occurring close to heading time can interfere with pollination and reduce yield.
- adverse environmental conditions around the time of application or crop emergence
  - Air temperature fluctuations of more than 20°C or daytime highs exceeding 30°C will dramatically increase the potential for herbicide injury.
  - Excessive rain after a soil-applied herbicide application can cause the herbicide to "splash up" on the leaves causing injury.

Crop growth stage, variety, stress, environmental conditions, tank-mix partners and adjuvants will all affect the potential amount and severity of crop injury. When the target crop is under stress, its ability to metabolize a herbicide is reduced, and injury may result. A herbicide's mode-of-action will also influence the severity of crop injury. In general, while contact herbicide injury may look worse, systemic herbicides will have longer-lasting injury, which may be more severe. Each herbicide's product label will have a precautionary section outlining circumstances that may increase the potential for crop injury. Review these sections to minimize the potential of herbicide injury.

See Table 12–4, *Classes of Herbicide Injury According to Their Location on the Plant*, opposite page.

Table 12–4. Classes of Herbicide Injury According to Their Location on the Plant

Location on the Plant	Injury Symptoms
Injury to Newly Emerged Seedling Plants (Plates 39–41, on page 285)	
Dinitroanalines (Group 3) (systemic – xylem mobile) e.g., Prowl, Treflan	• stunted plants that do not fully emerge from the soil • short, thick lateral roots • impact on yield will depend on severity of injury and crop stage at time of injury **Grasses** • shoots are short, thick and may appear red or purple **Broadleafs** • may have swollen and cracked hypocotyls (area below cotyledons)
Chloroacetamides (Group 15) (systemic – xylem mobile) e.g., Dual II Magnum, Frontier Max, Define	• stunting of shoots that result in abnormal seedlings that do not emerge • impact on yield will depend on severity of injury and crop stage at time of injury **Grasses** • grasses may leaf-out underground • shoots may be abnormal when leaves do not properly unfurl **Broadleafs** • crinkled leaves and/or shortened mid-vein, which produces "draw-string" effect or heart-shaped leaves
Injury Affecting Older Leaf Tissue (with the potential to move upward) (Plate 42 on page 285 and Plate 43 on page 286)	
Systemic Photosynthetic Inhibiting Herbicides (systemic – xylem mobile) **Triazines (Group 5)** e.g., Atrazine, Sencor, Princep Nine-T **Substituted Ureas (Group 7)** e.g., Lorox	• translocation occurs only in the xylem (upwards movement only) • injury symptoms occur after the cotyledons and first true leaves emerge • injury begins with yellowing of the leaf margins or tips and yellowing between the leaf veins • older and larger leaves are affected first • injured leaf tissue eventually turns brown and dies • injury is greater on higher pH soils (>pH 7.2) • impact on yield will depend on the severity of injury and the crop stage at which the injury occurred
Injury Limited to Plant Tissue Exposed at the Time of Application and With No Movement to New Plant Growth (Plates 44–48, on page 286)	
Non-Systemic Photosynthetic Inhibiting Herbicides (Group 6) (contact) e.g., Basagran, Pardner	• injury is confined to foliage that has come in contact with herbicide • typical symptoms include leaf speckling, blotching or bronzing and leaf tip burn • crop oil concentrates and other additives may intensify injury symptoms • injury is typically cosmetic with little to no impact on yield **Grasses** • grass plants are generally tolerant to the non-systemic photosynthesis inhibitors
Phosphorylated Amino Acids (Group 10) (contact with limited phloem & xylem mobility) e.g., Liberty, Ignite	• chlorosis and wilting usually occur within 3–5 days followed by necrosis within 1–2 weeks • symptoms occur faster in bright sunlight and high humidity • impact on yield is typically significant
Diphenylethers (Group 14) (contact) e.g. Reflex, Blazer	• reddish-bronze spotting of the leaf surface may appear shortly after application • spotting is highly correlated to the spray application pattern • plants that do not die may be stunted for a week or so • crop oils and other additives may increase plant injury • injury is typically cosmetic with little to no impact on yield
Bipyridiliums (Group 22) (contact) e.g., Reglone, Gramoxone	• injury occurs very quickly (1–2 days after application) • plant leaves will have a limp, water-soaked appearance, which is followed by browning of the leaf tissue • drift injury appears as blotching necrotic regions on leaf tissue • impact on yield can be significant • perennial plants affected will grow back
Additives (No specific group) Surfactant or 28% UAN injury	• severe browning or leaf tissue • new leaf tissue will be unaffected • most common with 28% UAN used as a carrier to apply herbicides in cereals or when an excessive rate of surfactant is used • largely cosmetic injury with negligible yield loss, provided visual injury is not severe

Table 12–4. Classes of Herbicide Injury According to Their Location on the Plant

Location on the Plant	Injury Symptoms
Injury Affecting New Growth and With the Potential to Move From Leaves to Roots (Plates 49–54, on page 287, and Plates 55–68, on page 288)	
Lipid Synthesis (ACCase) Inhibitors (Group 1) (systemic – phloem mobile) e.g., Assure II, Excel, Poast Ultra, Venture	• newer leaf tissue typically will be yellow or red, then turning brown; the leaves in the whorl will be decomposed and easy to pull out • symptoms develop slowly (7–14 days) • impact on yield is significant **Grasses** • injury on grass plants only
Amino Acid Synthesis Inhibitors (Group 2) (systemic – phloem mobile) e.g., Accent, Classic, Pinnacle, Pursuit, Ultim	• internodal stunting • leaf distortion with interveinal yellowing • underside of leaf may have red or purple veins • symptoms take 1–2 weeks to develop • impact on yield will depend on the severity of injury and crop stage at which the injury occurred
Growth Regulators (Group 4 – phenoxy acids) (systemic – phloem mobile) e.g., 2,4-D, 2,4-DB, MCPA, MCPA/MCPB	• broadleaf plants exhibit stem twisting and leaf malformations (cupping, crinkling, parallel veins, leaf strapping) • 2,4-D will lengthen petioles of trifoliate soybean leaf, whereas benzoic acid herbicides (i.e., Banvel II) will not • corn plants exhibit rolled leaves (onion leafing), fused brace roots, stalk bending (goose necking) and brittleness, and missing kernels • small grains exhibit twisted flag leaves, sterile florets, or multiple florets, twisted awns and head malformation • impact on yield will depend on the severity of injury and crop stage at which the injury occurred
Growth Regulators (Group 4 – benzoic acids) (systemic – phloem mobile) e.g., Banvel II, Distinct	• dicamba injury is similar to that caused by phenoxy acid herbicides • broadleaf plants may exhibit more cupping than strapping of leaf tissues • will cause more goose necking than 2,4-D in corn and lodging in small grain (especially wheat) • impact on yield will depend on the severity of injury and crop stage at which the injury occurred
Growth Regulators (Group 4 – pyridine acids) (systemic – phloem mobile) e.g., Lontrel, Milestone	• injury similar to phenoxy and benzoic acid herbicides • legume crops (soybeans, alfalfa, clovers) are extremely susceptible to the pyridine acids • impact on yield sensitive species is significant
Aromatic Amino Acid Synthesis Inhibitors (Group 9) (systemic – phloem mobile) e.g., Roundup, Weathermax, Touchdown Total	• plant foliage will first yellow (new leaves first) and then turn brown and die within 10–14 days after herbicide application • drift onto corn can cause reddening of leaf tissue • impact on yield is significant
Pigment Inhibitors (Bleaching Herbicides) Triazoles (Group 11) e.g., Amitrol 240 **Inhibitors of Carotenoid Biosynthesis (Group 13)** e.g., Command **HPPD Inhibitors (Group 27)** e.g., Callisto, Converge, Impact, Infinity	• injury begins with new leaf tissue turning white "bleached" colour then progressing to yellow, followed by brown necrotic tissue • impact on yield is generally minor, but if injury is severe, it can be significant

Insects & Pests

13. Insects and Pests of Field Crops

Insects and pests that infest and cause damage to more than one crop are described in *General Soil Insects and Pests*, below. Scouting techniques and management stategies are included for each crop. Information on insects and pests that cause damage to only one crop is listed in this chapter under the crop they invade. Recommended treatments to control these pests can be found in OMAFRA Publication 812, *Field Crop Protection Guide*.

OMAFRA Publication 812, *Field Crop Protection Guide*, a companion publication to this publication, is the source for information on integrated pest management options and insect, pest and disease control products. Visit the OMAFRA website at www.ontario.ca/crops.

General Insects and Pests

Soil Insects and Pests

GRUBS
corn, soybeans, forages, winter cereals
Various types of grubs can attack field crops. European chafer is the most common problem grub in Ontario field crops, although June beetle and Japanese beetle grubs also cause damage. Proper identification of the species of grub present in each field is important, as their life cycles are different, which influences the management strategies implemented.

Description: Grubs are white and C-shaped, with an orange-brown head and dark posterior. Correctly identifying the species of grub requires using a hand lens focused on the anal bristles known as "rasters" that are positioned on the underside of the larva at the last abdominal segment of the larva (posterior). Each species has a particular "raster" pattern. Identifying the species will determine when feeding activity is expected and when control measures can be implemented.

Damage: Grubs feed on the fibrous roots 3–5 cm (1–2 in.) from the soil surface. Roots are pruned, causing plants to become stunted and eventually wilt. Intense root feeding results in poor emergence and plant death. Crops at risk from grubs include corn, soybeans, wheat and forages. Fields near areas of turf such as lawns, golf courses and pasture, are particularly prone to grub infestations. Crop damage is dependent on the timing of planting and crop emergence in relation to larval feeding activity. If the crop is planted after the grub species has completed its larval stages (feeding stage of the insect), crop damage can be avoided. Additional damage can occur from predators such as skunks and raccoons that dig up and feed on the grubs, although the damage is seldom economical.

Figure 13–1, *Life Cycles and Feeding Periods for Common Grubs (European Chafer, June Beetle, Japanese Beetle)*, next page, shows the differences and similarities in their life cycles.

EUROPEAN CHAFER *(Rhizotrogus majalis)*
corn, forages, cereals
Description: European chafer larvae can be distinguished from other white grubs by their Y-shaped raster pattern (Plate 59 on page 288). The adult is a medium-sized, approximately 14 mm (½ in.), light-brown, oval, scarab beetle, closely resembling the native June beetle. Chafers are also known as the annual white grub.

Life History: The European chafer is an annual grub, having only one generation per year. Chafers over-winter as larvae or "grubs" in the soil below the frost line. In April, these larvae migrate upwards, close to the soil surface and feed on plant roots. European chafer is more cold tolerant than the other grub species and can feed as soon as the soil thaws, even before the snow melts. Larvae stop feeding by mid-May, then pupate from mid-May to mid-June. Adult beetles emerge from the soil in early June to early July to mate. Adult chafers congregate in conspicuous mating flights and can be seen swarming at dusk. The adult females then locate cool, moist soil in nearby fields or lawns to lay their eggs. Eggs hatch and newly hatched larvae begin feeding on roots in early August until the ground freezes. The grubs then migrate below the frost line to overwinter.

Damage: Spring feeding damage by chafer larvae starts in April and is completed by mid- to late May. Corn and forages are at the most risk, while soybeans tend to miss feeding activity when planted after mid-May. Fall feeding damage by chafer larvae is most evident in the winter wheat crop. Adults do very little to no feeding.

Scouting Technique: It is best to scout for chafers in the fall in standing soybean stubble fields. Scout for grubs on the sandier knolls of fields and in areas where past injury was evident. Using a shovel, dig up approximately 30 cm^2 (1 ft^2) of soil, roughly 7.5–10 cm (3–4 in.) deep, in at least five areas of the field. Sift through the soil by hand, breaking up any clumps and count how many grubs are found in each sample.

Insect	Jan–Mar	April	May	June	July	August	Sept	Oct	Nov–Dec
European chafer	3rd instar larvae – overwintering		3rd instar larvae – feeding and pupation	Adults emerge, mate & lay eggs – no feeding		1st instar larvae – feeding	2nd instar larvae – feeding	3rd instar larvae – feeding	3rd instar larvae – over-wintering
June beetle Yr 1	Adults overwintering in soil		Adults emerge, mate and lay eggs		Eggs hatch – 1st instar larvae – feeding		2nd instar larvae – feeding	2nd instar larvae – overwintering	
Yr 2	2nd instar larvae – overwintering		2nd instar larvae – feeding	3rd instar larvae – feeding				3rd instar larvae – overwintering	
Yr 3	3rd instar larvae – overwintering		3rd instar larvae – feeding	Pupation and adults remain in soil to hibernate and overwinter					
Japanese beetle	3rd instar larvae – overwintering		3rd instar larvae – feeding		Adults emerge, mate & lay eggs – no feeding	1st instar larvae – feeding	2nd and 3rd instar larvae – feeding	3rd instar larvae – overwintering	

Figure 13–1. Life Cycles and Feeding Periods for Common Grubs (European Chafer, June Beetle, Japanese Beetle) Damaging stages are shaded.

Action Threshold for Corn and Cereals: The presence of two or more larvae per square foot (30 cm^2) indicates the need for control.

Action Threshold for Forages: No thresholds are available, but two or more larvae per square foot (30 cm^2) indicates that control may be necessary, particularly in a first-year crop.

Management Strategies for All Crops:

- Cultural options include disturbing the soil by tillage or disking, which brings the grubs to the surface where they are exposed to the elements and natural enemies such as birds, skunks, raccoons, etc. For this strategy to be effective, plow in the fall before the grubs migrate below the plow depth.
- No rescue treatments are available.

Management Strategies for Corn and Cereals:

- Use an insecticide seed treatment that is registered for European chafer.
- If grub populations are high (i.e., four or more grubs per square foot), use the higher rate of an insecticide seed treatment.
- Avoid planting corn if the chafer population is extreme; plant soybeans instead.
- Plant crop into ideal soil conditions so that the crop will rapidly become established and able to tolerate low to moderate grub feeding.

Management Strategies for Forages:

- Avoid planting alfalfa if chafer populations are high. Plant other crops that have insecticide seed treatments available to reduce grub populations.
- A well-managed pasture with a good mix of legume and grass species may help reduce stand loss, as grubs tend to feed more on the grass species. Over-seeding or reseeding may be required for a few years to compensate for what the grubs have taken out.

JUNE BEETLE (*Phyllophaga* spp.) soybeans, forages

Description: June beetle larvae can be distinguished from other white grubs by their oval-shaped raster pattern, where two rows of rasters run parallel to each other (Plate 60 on page 288). The adult is slightly larger, roughly 20 mm (¾ in.), than European chafer and is reddish-brown to black in colour. The June beetle is also known as the true white grub or June bug.

Life History: June beetles have a 3-year life cycle. Adults emerge from the soil mid-May to mid-June and lay eggs. Adults tend to congregate at dusk in large masses on trees and shrubs to mate. Eggs are laid in moist soil and hatch within a few weeks. First instar larvae begin feeding on plant roots and molt into the second instar before migrating deep into the soil to over-winter. Once the soil warms up the following spring (Year Two), the second instars begin feeding and will remain as larvae throughout the year, molting once into the third instar. The second year of their life cycle is therefore the most destructive. Larvae again prepare to over-winter by migrating deeper in the soil once temperatures drop, until the following spring. In Year Three, the third instar larvae feed on roots for a short time before pupating and becoming adults. These adults will remain dormant in the soil for the rest of the season and only emerge the following spring.

Damage: Damage depends on which year of the life cycle the majority of the larvae are in. The second year of the life cycle is the most damaging, because there is a full growing season of the larval stage. Soybeans and forages tend to experience the most injury from this insect, especially when the crop is still young. Adults can feed on tree species and ornamental plants such as roses but do not feed on field crops.

Scouting Techniques: Scout for grubs on the sandier knolls of the field and in the areas where injury was evident in previous years. Using a shovel, dig up approximately 1 square foot of soil, (30 cm^2) about 7–10 cm (3–4 in.) deep, in at least five areas of the field. Sift through the soil by hand, breaking up any clumps and count how many grubs are in each sample.

Action Threshold: No thresholds are available for June beetle grubs, though two or more larvae indicate the need for control.

Management Strategies for All Crops:

- Use insecticide seed treatments in fields with a history of damage, particularly if grubs appear to be mainly in the second year of their life cycle when the majority of the feeding will take place.
- Avoid planting early in cool, wet springs.
- Plant in ideal soil and weather conditions to help promote rapid germination and seedling growth.
- No rescue treatments are available. Tillage can help kill some of the larvae and expose them to their predators such as birds, skunks and racoons.

Management Strategies for Forages:

- Avoid planting forages in infested fields, particularly if grubs appear to be mainly in the second year of their life cycle, when the majority of the feeding will take place.
- Plant fields with a history of crop loss due to grubs to another field crop that has an insecticide seed treatment available for grub control. Re-assess the grub population following this control tactic to determine if forages can be planted in that field again.
- A well-managed pasture with a good mix of legume and grass species may help reduce stand loss, as grubs tend to feed more on the grass species. Over-seeding or reseeding may be required for a few years to compensate for what the grubs have taken out.

JAPANESE BEETLE *(Popillia japonica)*
soybeans, forages

Description: Japanese beetle grubs can be distinguished from other grubs by the wide, shallow V-shaped raster pattern (Plate 61 on page 289). The grubs are also much smaller in size than European chafer and June beetle grubs. The adult beetles are approximately 13 mm (½ in.) in length and can be easily identified by their bright, metallic-green head and coppery wings tinged with green edges (Plate 62 on page 289). They have 12 white tufts of hair along the boundary of their wings.

Life Cycle: Japanese beetles have only one generation a year. They over-winter as third instar larvae below the frost line. Once the soil has warmed up above 15°C, the larvae migrate to the surface and feed on plant roots until mid- to late June, after which time they pupate to become adults. Adults emerge in early July and live for approximately 40 days. Once mated, females lay their eggs in the soil, which hatch in a few weeks. Larvae begin feeding on roots, molting through three instars before preparing for over-wintering by migrating below the frost line by early October.

Damage: Both the larval and adult stages can feed on field crops. This pest is most commonly found in the Niagara/Hamilton region, though it is known to be present across Ontario. Soybean and hay fields in particular tend to experience some root-feeding damage from the larvae. Adults will also feed on soybeans, dry edible beans, fruit crops and ornamental plants, causing leaves to appear skeletonized.

Scouting Technique for Larvae (Grubs): Scout for grubs on the sandier knolls of the field and in the areas where past injury was evident. Using a shovel, dig up approximately 1 square foot of soil (30 cm^2), about 7–10 cm (3–4 in.) deep, in at least five areas of the field.

Scouting Technique for Adults in Soybeans: Scout 20 plants in at least five areas and compare the damage found to Figure 13–2, *Defoliation Chart for Soybean Leaf-Feeding Insects*, on page 210.

Action Threshold for Larvae (Grubs): No thresholds are available for Japanese beetle grubs, though two or more larvae indicate that control may be necessary.

Action Threshold for Adults in Soybeans: If the defoliation exceeds the thresholds in Table 13–3, *Standard Damage Thresholds for Soybean Insect Defoliation*, on page 211, a rescue treatment may be warranted to prevent excessive yield loss.

Management Strategies for All Crops:

- Use insecticide seed treatments in fields with a history of damage by the larvae.
- Avoid planting early in cool, wet springs. Plant in ideal soil and weather conditions to help promote rapid germination and seedling growth.
- No rescue treatments are available for grubs. Tillage can help kill some of the larvae and expose them to their predators such as birds, skunks and raccoons.
- For further recommendations on adults, see *Defoliating Insects*, on page 210.

WIREWORM (*Limonius* spp. and others)

corn, soybeans, cereals, dry edible beans

Description: Wireworms are larvae that are 7–35 mm (¼–1⅓ in.) long, cylindrical, copper-brown-coloured and hardened (Plate 63 on page 289). Adult wireworms are beetles that have the ability to flip themselves upright when placed on their backs. As they flip there is an audible click, giving them their name "click beetles."

Life History: Wireworms take up to 6 years to develop from egg to adult, spending most of their life as larvae. They over-winter as larvae in the soil below the frost line. When soil temperatures warm in the spring, the larvae move to the surface to feed. Due to their long life cycle, the larvae can damage several successive crops, feeding on the roots of weeds, grasses and crop plants. Once soil temperatures become hot, and soil moisture decreases, the larvae migrate downward and may be difficult to find. As they become adults, the larvae migrate back to the surface, pupate and the adult emerges to mate and lay eggs in grasslands or weedy areas.

Damage: Wireworms are most active during the months of April to June and occur most often in fields that have little disturbance. The larvae attack roots, seeds and germinating seedlings of many crops such as corn, soybeans, spring cereals, dry edible beans and potatoes. Non-uniform growth or gaps in the stand may be due to wireworm feeding on germinating seeds. Injured seedlings appear stunted and wilted, with leaves sometimes becoming purple or blue at the tips. Wireworms are rarely a problem in fall-planted cereals, however, they can be serious in spring-planted grains. The problem is usually worse in the second year after sod, following years with high grassy-weed pressure or when corn and cereals are frequently in the rotation. They are also generally more prevalent in sandier soils, especially on the knolls.

Scouting Technique: The best time to scout is in mid-April, a few weeks before planting; if soil moisture and temperatures are adequate, fall sampling is also possible. Establish two bait stations per "high-action" site in each field. Dig a hole at each station, approximately 15 cm (6 in.) wide and 5–8 cm (2–3 in.) deep. Choose one or two high-action sites in the field (i.e., sandy knolls, heavy grass infestations). Bury a nylon mesh bag with 1 cup equal parts untreated and soaked corn and wheat or freshly cut potatoes at the bottom of the station. Mound the soil over the bait to prevent standing water. Securing a dark piece of plastic over the mound will help warm the bait station, increasing the fermentation of the bait, which will be more attractive to the wireworms. Place a flag at the bait station to make it easier to find again. Return to the stations a few days before planting to sift through the bag contents and record the number of larvae found per station.

Action Threshold: One wireworm per bait station.

Management Strategies for All Crops:

- Use insecticide seed treatments or in-furrow or banded soil insecticides in fields that have reached threshold, have a history of wireworm incidence or are following grassy sods.
- No rescue treatments are available. However, controlling grassy weeds in crops previous to corn will help with prevention.

MILLIPEDES (various species)

corn, soybeans

Description: Millipedes are not insects but arthropods. They are hard-shelled, cylindrical and approximately 2.5–5 cm (1–2 in.) long. They get their name (milli: thousands, pedes: legs) from having many legs — two short pairs of legs per body segment in the adult stage. Adult millipedes are dark reddish-brown to grey-black in colour and have hardened bodies, while the immature millipedes are white, have fewer legs and do not have hardened bodies. As they mature, they develop more legs and turn darker in colour. Another distinguishing characteristic is that they coil up tight when disturbed.

> Do not confuse millipedes with wireworms; wireworms are coppery-brown in colour and only have six legs.

Life History: Both adult and immature millipedes over-winter in the soil under debris, rocks, etc. They can live for several years in the soil, taking up to 5 years to mature to the adult stage. They have become more prevalent with the adoption of reduced or no-till systems because of the increase in surface residues.

Damage: Millipedes are typically beneficial. They help decompose organic matter and feed on other insects. However, when planting too early in cool, wet springs, conditions are ideal for millipedes to feed on the seeds and young seedling roots, particularly corn and soybeans. No-till fields with higher residue soils and lots of organic matter are at higher risk, though damage has also been experienced in conventional fields. Deep planting can also promote injury. Droughty conditions will lessen their impact.

Scouting Technique: There are currently no established scouting methods for millipedes. Inspect roots, germinating seed and soil around areas with gaps in the plant stand. Millipedes could still be present on the roots or within the seed. If early-season injury is noticeable but no pest is present, setting up wireworm bait stations consisting of entirely soaked corn seed near the gaps in the stands will also be effective at capturing millipedes to determine their presence and eagerness to feed on corn seed.

Action Threshold: No threshold is available at this time.

Management Strategies for Corn and Soybeans:

- Insecticide seed treatments have not been found to be effective at controlling millipedes. No rescue treatments are currently available.
- Plant in ideal conditions to improve seed germination in these fields, particularly when cool wet springs are forecasted.

SEEDCORN MAGGOT *(Delia platura)*

corn, dry edible beans, soybeans

Description: The seedcorn maggot is a small, yellowish-white, headless, legless larva (Plate 64 on page 289). The body tapers to the front with two small mouth hooks protracting. The maggots burrow into germinating seeds and the below-ground parts of emerging seedlings, producing weak seedlings. The adults resemble a small housefly that is slender, light grey and approximately 5 mm (⅕ in.) in length.

Life History: The seedcorn maggot over-winters in the pupal stage. Adults emerge in early spring. Once mated, female adults (flies) search for an egg-laying site from April until the middle of June. The females are attracted to moist soils that give off an odour of decaying organic matter, such as crop residues, areas where manure has been applied or freshly tilled soil. Weeds are also attractive to females. The adults lay their eggs in the soil. The larvae then develop in the soil and organic residue, feeding on germinating seeds.

Damage: Seedcorn maggot is usually a problem during cool, wet springs when germination is delayed. The maggots feed on the swollen, ungerminated seed. They can be found in the cotyledon, embryo and hypocotyl. They can also mine the stem of the young seedling. Slow emergence and/or reduced stand establishment can occur. Damaged seedlings that germinate often die or lag behind.

Scouting Technique: Unlike wireworm, seedcorn maggot damage is usually found over a generalized, large portion of the field. Nothing can be done to rescue a damaged field except replanting if necessary. High-risk factors include freshly tilled soil with heavy crop residue, recently applied manure, recently tilled green manure, deep planting and early planting followed by cool, wet spring conditions. Look for signs of poor stand emergence and feeding damage at the base of the newly emerging plants.

Action Threshold: No threshold is available at this time.

Management Strategies:

- Consider insecticide seed treatments or in-furrow, soil-applied insecticides in early-planted fields where large amounts of manure or residue have been recently incorporated.
- Use good-quality seed that will emerge quickly.
- Plant in good soil conditions when cool wet weather is not in the forecast to ensure rapid seedling emergence.
- There are no rescue treatments available. Use an insecticide seed treatment or in-furrow insecticide in fields requiring replanting.

SLUGS *(Deroceras reticulatum)*

corn, soybeans, newly seeded forages, canola

Description: Juvenile and adult slugs are soft-bodied, legless, greyish or mottled in appearance and have a slimy or gelatinous covering that protects them from drying out. They are essentially snails without a shell. The head has two pairs of tentacles. Slugs usually range from 1–3 cm (⅓ in.) in length but can reach up to 10 cm (4 in.).

Life History: There is one generation per year but two populations, one maturing as adults in spring and one maturing as adults in fall. Therefore, damage can occur both in the spring and the fall on young developing plants. Both eggs and adults over-winter. Juvenile slugs hatch from eggs in the spring and the fall and are the most damaging stage of the pest. Slugs are most active during cool and wet periods in spring and fall and prefer environments with high humidity and relatively cool temperatures. Debris, such as crop litter or manure, provides them with shelter from the sun.

Damage: Slugs feed above or below ground, depending on the moisture level. They can feed on germinating seeds and seedlings, with no real preference for a plant part (Plate 65 on page 289). Slugs feed on lower parts of larger plants, partly or completely eating through leaves, resulting in ragged holes that cause a skeletonized appearance on leaves (Plate 66 on page 289). Feeding can resemble hail damage, and severe defoliation can result. If slug populations are high, they may feed on germinating seeds, hollowing them out before they can emerge. Higher-risk fields include no-till corn, soybeans and canola, especially fields with considerable crop residue, wheat fields underseeded with red clover, newly seeded alfalfa and fields following forages, especially grasses. Knowing the slug population of each field in the fall will indicate how significant the problem will be the next spring. It is the same population that over-winters and feeds in the spring.

Scouting Technique: Scout for slugs at night or in the early morning hours, when they are active (nocturnal). Look for gaps in the stand, stripping of leaf tissue and/or small holes chewed in the leaves. Check under debris and clumps of soil. A certain sign of slugs is a slimy, silver-coloured trail on the plants or soil. To determine population levels, take small pieces of plywood, approximately 0.6–0.9 m (2–3 ft) long, or roofing shingles and position them on the soil surface in fields that have been harvested. Use 10–15 boards randomly scattered across the field to provide a good indication of population levels. These boards will act as shelters for the slugs. Visit the boards every 5 days for approximately 1 month, counting the number of slugs present under the boards. Morning is the best time to look, since slugs will still be in their shelters.

Action Threshold: No action thresholds are available. If slugs are commonly found under monitored boards as described above, the field should be considered at high risk for slug injury in the spring. Scout these fields again in the spring to confirm risk. Young seedlings and germinating seeds are most impacted.

Management Strategies:

- Planting into conditions that help the crop grow quickly can avoid heavy slug damage.
- Tillage can be used against slugs since the elimination of the crop cover exposes the slugs to dehydration and predation by birds and mammals. Zone tillage or row sweepers can help speed up the drying of the row area, thus deterring slug feeding. Moving trash away from seedlings may help reduce damage.
- There are presently no economically feasible chemical methods available for slug control in field crops. Slug baits are available for field crops but are very expensive and are only recommended for use in small problem areas of the field. Apply baits shortly after May 24 to achieve the highest potential for success.
- Experiments with 28% nitrogen/water mixtures or foliar potash applications have proven to be inconsistent and are not encouraged.

Corn Insects and Pests

Table 13–1, *Corn Insect Symptoms in the Field*, opposite page, shows symptoms of corn insects and pests.

This section describes insects and pests that affect only corn. The insects and pests listed below affect corn as well as other crops.

European chafer	page 195
Japanese beetle	page 197
June beetle	page 196
Millipedes	page 198
Seedcorn maggot	page 199
Slugs	page 199
True armyworm	page 219
Wireworm	page 198

BLACK CUTWORM *(Agrotis ipsilon)*

Description: Larvae are greyish-black with a paler underside and no distinct markings on their bodies (Plate 67 on page 290). Mature larvae are about 3.5 cm (1¼ in.) long and hide in the soil during the day. They can be found near freshly cut plants, under soil clumps or along a poorly closed seed furrow. Adult moths are grey with a small black dagger marking on each forewing.

Life History: Cutworm moths do not over-winter in Ontario but are carried in from the south on strong southerly weather systems. The heaviest immigration occurs from April to May but may occur as early as March. Cutworms are therefore more frequent in fields with green cover early in the spring. There are several generations per year, however, only the first generation causes economic damage in corn. Warm, clear, calm nights in early spring are ideal for moths to lay eggs. Eggs are laid on dense vegetation, low to the ground, and are usually laid before primary tillage in the spring. In fields with vegetation present before planting, larvae will develop on the weeds until the crop has emerged. In this situation, the larvae that move over to the crop will be larger and more difficult to control. Feeding occurs from early May through to mid-June.

Damage: Fields located along Lake Erie experience frequent cutworm infestations. Plants attacked by young larvae will have small holes or gouges in the leaves. Plants may suddenly wilt, because the stem has been hollowed out or fed on underground. Larger larvae cut off the plant at or just below ground level. Factors that favour cutworm outbreaks include a history of cutworm damage, presence of winter annual weeds such as chickweed and volunteer wheat before planting, no-till and heavy crop residue.

Scouting Technique: Start scouting for cutworm once every 5 days as soon as corn emerges. Scout at least five locations for every 10 ha (25 acres) of field. Pay particular attention to those areas where weeds were heavy just before tillage and planting. Look for leaf-feeding (pinholes) by young climbing larvae as the first sign of damage. Also look for wilting plants, foliage-feeding or for plants being cut off at the ground. Dig around damaged plants and search through the soil, as cutworms like to hide in the soil during the day. Note the size of the cutworms found.

Action Thresholds: If more than 10% of plants show leaf feeding, treating with a foliar insecticide will give nearly 100% control. Once corn reaches the five-leaf stage and begins to produce roots at the base of the plant, the risk has passed. Cutworms that are nearly mature (over 2.5 cm long) are difficult to control with insecticides and will stop feeding in a few days when they reach full size.

Table 13–1. Corn Insect Symptoms in the Field

Symptom	Insects and Pests															
	Grubs	Wireworms	Millipedes	Seedcorn maggot	Slugs	Black cutworm	Corn flea beetle	True armyworm	Potato stem borer	European corn borer	Corn rootworm larvae	Corn rootworm adult	Western bean cutworm	Corn earworm	Fall armyworm	Corn leaf aphid
Gaps in the stand																
Seed is fed upon or hollowed out		x	x	x	x											
Plants are stunted or wilting	x	x	x			x			x							
Plants are cut off at or below soil level						x			x							
Leaf tissue feeding																
Feeding holes are ragged					x	x		x							x	
Entire leaf eaten away except for midrib								x								
Pinholes or round, symmetrical holes										x						
Feeding tracks running parallel to leaf veins on upper surface of leaf							x					x				
Stalk damage																
Tunneling within the stalk									x	x						
Stalk "goosenecked"											x					
Ear damage																
Large chunks or kernels missing:																
entry hole on side of ear and feeding throughout ear													x		x	
no entry hole into ear and feeding concentrated on ear tip														x		
Surface feeding on kernels and/or husk tunneling										x						
Silks clipped												x	x	x		
Ears drop										x						
Tassel damage																
Broken tassels										x						
Tassels discoloured or sticky																x
Tassels are fed on										x			x	x	x	

Management Strategies:

- Using seed treatments specifically for black cutworm control is not recommended, since cutworm is a sporadic pest. For fields with a frequent history of cutworm injury, consider planting Bt corn hybrids containing Cry1F and/or using an insecticide seed treatment at planting. These products are most effective on younger larvae.
- Foliar insecticide treatment is most effective when applied to the soil soon after cutworms have hatched. Cutworms are most active in the evening, so insecticides applied at night/evening are more effective. Foliar insecticide application to mature larvae (larger than 2.5 cm or 1 in.) is not recommended since most of the damage has occurred and control may be inadequate.
- It is not necessary to treat the entire field, only those areas showing evidence of feeding.
- In no-till corn fields, it is important to remove green vegetation that could attract the moths in early spring. Fall burndown of volunteer crops and weeds is recommended. Fields should be bare for at least 2–3 weeks before planting.

CORN FLEA BEETLE *(Chaetocnema pulicaria)*

Description: Very tiny (1.8 mm), black, shiny beetles with elongated hind legs, which are used for jumping when disturbed (Plate 68 on page 290).

Life History: This pest over-winters as adults at the base of grasses. In the early spring, beetles emerge, and mated females then lay their eggs in the soil close to the base of corn plants. Within 6 days, eggs hatch into larvae, which then pupate. Within 14 days, the adult beetle emerges from the soil. There are three to four overlapping generations per year. Only those generations occurring from early-May to late-June, during corn emergence, are considered a potential problem.

Damage: Planting seasons following mild winters experience higher beetle activity. Only susceptible varieties and seed corn inbreds show yield loss. Long feeding scratches or window-paning are found on the leaves, usually running parallel with the leaf veins.

Flea beetles are vectors of Stewarts' bacterial wilt, which over-winters in the gut of the insect. Symptoms of Stewarts' wilt include linear lesions on the leaves with wavy edges. Plants may wilt or become stunted from this disease.

Scouting Technique: Scout every 4–5 days. Inspect five sets of 20 seedling plants per field to determine the presence and density of the beetle.

Action Thresholds: For susceptible varieties, 6 beetles per 100 plants prior to the fifth-leaf stage warrant control. For tolerant varieties, an average of five or more beetles per plant prior to the fourth-leaf stage may warrant control.

Management Strategies: Models help predict the risk of high adult activity each year based on winter temperatures and adult survival.

- Use insecticide seed treatments on susceptible hybrids and inbreds, and for those fields with a history of flea beetle activity.
- Avoid early planting dates for varieties susceptible to Stewart's wilt. Plant fields with a history of Stewart's wilt to resistant hybrids.
- Additional foliar sprays may be necessary for seed corn and susceptible varieties if populations are very high. It is not economical to spray corn with insecticides to protect against the flea beetles transmission of Stewart's wilt except for highly susceptible inbreds and hybrids.

POTATO STEM BORER *(Hydraecia micacea)*

Description: Larvae are light purple to pink, and approximately 4 cm (1½ in.) in length when mature (Plate 70 on page 290). Adults are brown moths that are active during August and September.

Life History: This pest is more severe in the eastern counties, but infestations occur throughout the province. There is one generation per year. This pest over-winters as eggs on grasses. Eggs are laid in two or three parallel rows under the leaf sheath. These hatch in late April, and the small larvae initially bore into the stalks of grass plants. By late May, the larvae outgrow the grass stalks and move to nearby thicker stalk crops such as corn. These larvae continue to feed until late June, pupate and emerge as adults in late July.

Damage: Larvae are the only damaging stage. Damage is usually most severe at field edges or near grassy, weedy areas. Larvae feed on plants in late May through early June. On young plants, the larvae will burrow into the base of the plant, below the soil line. Plants may be cut at the base, similar to cutworm injury. At the three or more leaf stage, they feed inside the whorl at the base of the corn plant, causing the upper one or two leaves to wilt, while the lower part of the plant remains healthy. Fields at higher risks include grassy or weed-infested fields the previous year; fields following sod and conservation-till fields.

Scouting Technique: The larvae are usually found within the stem or in soil near the base of the plant. Look for potato stem borers along fencerows or in grassy areas.

Action Threshold: No threshold is available at this time.

Management Strategies:

- There is no effective or economic chemical control for this insect, since the borer remains inside the plant where it is protected.
- Good weed control, especially of grassy weeds, is effective in reducing the risk of damage next year.
- Fall plowing or burndown can reduce the number of over-wintering eggs. Parasitic wasps generally keep this pest below economically damaging levels.

TRUE ARMYWORM *(Pseudaletia unipuncta)*

True armyworm is an important pest of corn. For information on this insect, see page 219.

EUROPEAN CORN BORER *(Ostrinia nubilalis)*

Description: European corn borer (ECB) egg masses are flat, creamy white and layered over each other, making the egg mass appear similar to fish scales (Plate 71 on page 290). Mature larvae are creamy white to pale grey with 2 small spots per abdominal segment, approximately 2.5 cm in length and have a black head (Plate 72 on page 290). Adults are light-brown moths approximately 2 cm long with dark wavy lines running across each forewing (Plate 73 on page 291). Male moths are darker and smaller than females.

Life History: There are two distinct strains in Ontario. South of a line from Sarnia to Simcoe, a bivoltine strain can undergo multiple generations (typically two), depending on the length of the season. North of this line, a univoltine strain has only one generation per year. There is a band of overlap for these two strains, about 50–80 km wide along this line.

The insect over-winters as larvae in corn stalks and other residue left on the surface from the previous growing season. As day-length increases and average day temperatures exceed 10°C, the larvae pupate. Pupae are found within larval feeding tunnels and require 2 weeks to develop before adults emerge.

While emergence begins around the third week of May in the southernmost regions of the province, moths do not usually appear until mid-June in Eastern Ontario. Once moths emerge, they fly to nearby "action sites" or vegetative habitats, such as fencerows, ditches and hedgerows along fields.

Once mated, females leave the action sites to lay eggs on the host crop. Eggs are generally laid on the underside of leaves, close to the midrib. Where univoltine ECB are present, larvae develop through the season until autumn, when as fifth instars they prepare for over-wintering. Where bivoltine ECB are present, first-generation larvae will pupate in mid-summer, emerge as adults and complete a second generation before entering diapause in the fall.

Damage: Early-season larvae feed on leaves, creating small pinholes and eventually migrate into the whorl of the plant and attack the enclosed tassel. Later-season larvae feed briefly on the leaves, bore into the midrib of the leaf and then migrate into the stalk of the plant and husk of the ear. Larvae may also feed directly on the developing kernels. Stalk lodging and ear droppage may occur as a result of significant infestations. This pest can carry both stalk rots and ear rots into the plant. High-risk factors include no-till fields with high residue, those with frequent corn crops in the rotation, regions with a high percentage of corn (50% or greater in region) and regions where univoltine and bivoltine strains overlap.

Scouting Technique: Early-season moths are attracted to taller, early-planted corn fields while second-generation corn borer female moths are attracted to later-planted fields that are silking/tasselling. Examine a minimum of five sets of 20 plants per field (100 plants per field).

First generation scouting — Look for leaf-feeding damage. Pull out and unroll the whorl of the damaged plants, looking for small larvae. Split the stalk of the plants from top to bottom to locate older larvae. Record the percentage of damaged plants and number and size of larvae found.

Second-generation scouting — Look for egg masses on the underside of leaves close to the midrib of the plant. Concentrate scouting efforts to the three leaves above and below the ear of the plant. Record the percentage of plants with egg masses. Repeat scouting every 5–7 days until peak moth flights have subsided (approximately 1 month).

Economic Thresholds for Non-Bt Corn Hybrids: See Appendix G, on page 264, to calculate ECB economic thresholds for field corn. For seed corn, see the publication *Seed Corn Best Management Practices for Ontario*, available at www.seedcorngrowers.on.ca.

Management Strategies for Non-Bt Corn Hybrids:

- Insecticides have generally not provided economic control of ECB in field corn.
- When ECB Bt corn hybrids cannot be used, select non-Bt corn hybrids with resistance or tolerance to ECB feeding that have good agronomics.
- Shredding debris after harvest is an effective way to destroy borers over-wintering in stalks and stubble. Leave as little stalk as possible.
- Immature stages of ECB are attacked by natural enemies, which contribute to reducing population densities. Predators such as lady beetles and minute pirate bugs feed on the eggs and young larvae. Parasitic wasps and predaceous mites can also help control this pest.

Management Strategies for ECB Bt Corn Hybrids:

- If ECB is a moderate-to-high risk in your region, consider planting transgenic Bt corn hybrids that control ECB. Use Bt hybrids that express the Bt toxin in the ear as well as the stalk to help avoid stalk and ear rot.
- If ECB Bt corn is planned, the Canadian Food Inspection Agency requires that insect resistance management strategies be followed. This requirement is endorsed by the Canadian Corn Pest Coalition.

The insect resistance management strategies include:

- planting a non-Bt refuge to reduce the risk of developing resistance to Bt. Where the refuge needs to be planted in relation to the Bt hybrid and what percentage of the total corn acreage of refuge is required depends on the Bt hybrid used and the pest being targeted.
- placing the refuge and the ECB Bt corn hybrid within 100–150 CHUs of each other to be equally attractive to the adult moths.
- using no foliar insecticides in the refuge.

The Canadian Corn Pest Coalition website, www.cornpest.com, and the publication, *A Grower's Handbook: Controlling Corn Insect Pests With Bt Corn Technology*, provide specific refuge requirements and ECB biology.

Growers planting stacked Bt corn hybrids containing both ECB and corn rootworm (CRW) Bt must follow the CRW refuge requirements outlined for corn rootworm.

CORN ROOTWORM *(Diabrotica virgifera and Diabrotica barberi)*

Description: There are two species of corn rootworm (CRW) in Ontario. Western corn rootworm (WCR) adults are yellow to green with three black stripes on their wings (Plate 75 on page 291). The females typically have three wavy black stripes on their wing covers while the three stripes on males are fused and are undifferentiated. Male WCR adults are also slightly smaller, and their antennae are longer. Northern corn rootworm (NCR) adults are uniformly green to yellowish-beige with no particular markings that differentiate males and females (Plate 76 on page 291). Larvae are white with a brown head and a distinct dark tail plate. They are approximately 1 cm (½ in.) in length (Plate 74 on page 291).

> Do not confuse the western corn rootworm with the striped cucumber beetle. The striped cucumber beetle's abdomen on the underside is black, and its stripes are distinctly parallel, not wavy.

Life History: Both WCR and NCR are uniformly distributed across Ontario. In Southwestern Ontario, WCR predominate with a ratio of greater than 4:1, WCR to NCR. In Eastern Ontario and Quebec, the ratio is opposite, with 8:1 NCR to WCR. Both have only one generation per year. Eggs are deposited in the soil from July until a killing frost in the fall. The eggs over-winter and begin hatching in early June. Adults emerge in late July where they feed on silks and tassels.

Damage: Both adults and larvae feed on corn. Larvae feed on and within the roots from mid-June to mid-July, interfering with nutrient and water uptake, causing stress to the plant. Larger larvae feed on the brace roots, reducing the stability of the plant, causing it to lodge or gooseneck. Adults feed on pollen and clip the silks, interfering with pollination. If tassels and ears have not emerged, they will feed on the leaves, stripping tissue on the underside of leaves between the veins, leaving "window panes." Risk factors include continuous corn fields, fields with high beetle populations in corn from previous seasons or being the latest field planted in the previous season.

Scouting Technique: Monitor 20 plants in five different locations in your field weekly from when adults emerge at the end of July to the end of August.

Action Thresholds: If there is less than one beetle per corn plant on average throughout the month of August, then no insecticide to control CRW larvae is necessary in the following corn crop (**Note:** 1 WCR = 2 NCR when counting adults). Field corn can withstand heavy adult activity, usually requiring at least 10 adults per ear before control is necessary, but seed corn may require control if adult populations are causing extensive silk clipping, disrupting pollination. Dry conditions may keep the plants from growing more silk to compensate for the feeding injury. Treatment is warranted when the silks are on average being clipped down to within 1.25 cm (½ in.) of the ear tip. After pollination is complete, beetle feeding no longer poses a threat to yield.

Management Strategies:

- Crop rotation is the best strategy and is superior to insecticides for reducing rootworm populations. Since corn is the primary host crop, avoid planting corn on corn. Continuous corn fields produce up to 4 million beetles per hectare.
- Although rootworm insecticides can protect the crop from damage, on average they reduce beetle emergence by only 25%.
- If crop rotation is not practical, it may be necessary to treat fields of continuous corn with high rate insecticide seed treatment, soil-applied insecticide or to plant transgenic CRW Bt hybrids.
- If extensive goose-necking occurs or monitoring for adults in August shows significant populations, and corn is targeted for the field next year, use of a control strategy is required for the following crop.

> Rootworm is one of the most adaptable insect pests and has developed resistance to many forms of control used against it. Therefore, it is very important to use control products against this pest only when necessary.

Management Strategies for CRW Bt Corn Hybrids and Stacked Hybrids Containing Both ECB and CRW Bt:

- If planting CRW Bt corn hybrids, you must plant a refuge to reduce the chance of developing resistance to Bt. This is a requirement set by the Canadian Food Inspection Agency and endorsed by the Canadian Corn Pest Coalition.
- Where the refuge needs to be planted in relation to the Bt planting and to what percentage of the total corn acreage depends on the Bt hybrid used and the pest being targeted.
- For all Bt hybrids that contain Bt to control CRW, you must follow the refuge requirements for CRW Bt, even when the hybrid also controls ECB, since CRW pose a much greater risk of developing resistance to Bt products.
- Refuge and CRW Bt corn hybrid must be of similar maturity (within 100–150 CHUs), and the cropping history must be the same for both the refuge and CRW Bt plantings. No foliar insecticide spraying is permitted in the refuge or Bt plantings.
- Insecticide seed treatment is permitted in both the refuge and Bt plantings.

- For further information on specific refuge requirements and corn rootworm biology, see *A Grower's Handbook: Controlling Corn Insect Pests With Bt Corn Technology*, a publication available on the Canadian Corn Pest Coalition website at www.cornpest.com.

WESTERN BEAN CUTWORM *(Striacosta albicosta)* corn, dry edible beans

Description: Western bean cutworm (WBC) larvae are tan to pink in colour and do not have warts or spots (tubercles) on them, unlike European corn borer. The only distinguishing marking WBC larvae have is on their pronotum, the shield-like structure just behind the head of the larvae. The WBC's pronotum has two broad dark brown stripes. Adult moths are easy to identify from other corn pests. Each wing of the moth has a white band running along the edge or margin of the wing and has a spot or "moon" and boomerang-like mark on it (Plate 77 on page 291). Eggs are laid in masses of 5–200 eggs. WBC eggs are the size of a pin head, pearly white when first laid and are shaped like tiny cantaloupe (Plate 78 on page 291). As the eggs mature, they turn tan and then purple in colour. Eggs hatch in about 5–7 days.

Life History: Western bean cutworm is native to North America, though it has resided mainly in the Southwestern U.S., until its recent range expansion northeast across the Midwest and now into Ontario. WBC over-winter in other regions (though it is expected to successfully over-winter in Ontario) as larvae in soil chambers. Adult moths emerge and are actively flying by early June through early July. They lay eggs on the upper leaf surface of the upper leaves of the corn plants and prefer hybrids that hold their leaves upright. Adults prefer fields in the whorl-to-pretassel stages of corn. Once the corn crop is in tassel or beyond, they prefer to lay their eggs on the dry bean crop. Eggs hatch within a week. Unfortunately, the larvae are very mobile and can disperse from the original egg site to other plants in the vicinity both up and across corn rows. High-risk fields include no-till fields and fields with sandy soil.

Damage in Corn: Young larvae feed on the tassels and silks until they are large enough to tunnel into the ear and feed extensively on the kernels. In whorl-stage corn, larvae will feed on the developing pollen. Entry holes can sometimes be seen on the outside of the husk though they can also enter through the silk channels. Unlike corn earworm, western bean cutworms are not cannibals and therefore multiple larvae can feed on the same ear. Additional impact to quality can be expected from ear rots and secondary pests that may come in and feed on the damaged ears.

Damage in Dry Edible Beans: Damage begins as leaf feeding, but once the larvae get bigger, they will move to feed on and into the pods and seeds.

Scouting Technique in Corn: Scout 20 plants in five areas of the field. Focus efforts on the top three-to-four upper leaves of the plant. Look for egg masses and young larvae. Pheromone traps can be used to monitor for moth flight, which will indicate when eggs are being laid in the field and when to initiate scouting efforts. Contact the provincial entomologist for pheromone trap configurations, supply sources and monitoring protocols.

Scouting Technique in Dry Edible Beans: Thresholds are based on monitoring adults through pheromone traps first to indicate if and when scouting is necessary. Contact the provincial entomologist for pheromone trap configurations, supply sources and monitoring protocols. Monitoring with traps consists of placing two WBC pheromone traps per bean field. Place traps on opposite sides of the field no later than the last week of June and monitor them through the growing season. Moth catch totals are accumulated over time until peak flight occurs. When adult populations start to decline from last week's counts, the previous week was the peak flight. This requires checking traps regularly to ensure all moths are counted.

Action Threshold in Corn: Spray is warranted if 5% of the plants have eggs or small larvae. If the eggs have hatched, spray at 95% tassel emergence or if tassels are already emerged, when most of the eggs are expected to hatch.

Action Threshold in Dry Edible Beans: If the accumulated moth catch is less than 700 moths per trap, there is low risk of reaching damaging levels in that field. If the accumulated catch is between 700 and 1,000 moths, damage risk to beans is moderate and beans must be scouted closely. Check fields for larvae and larval feeding 10–20 days after the peak, and spray if pod feeding is found. If the catch exceeds 1,000 moths by the peak, risk is high for damage in dry bean and an insecticide application is needed 10–20 days after peak flight. Spray any edible bean field that is neighbouring a corn field that has reached threshold for WBC.

Management Strategies for Corn and Dry Edible Beans:

- Transgenic Bt corn hybrids containing Cry1F protein provide some protection from WBC.
- Foliar insecticide timing is critical. Once the larvae enter the corn ear, or bean pod, insecticides are no longer effective.
- Timing of application must coincide with egg hatch when young larvae are feeding.
- Deep tillage can help disturb and kill larvae over-wintering in soil chambers.
- Heavy rain can reduce young larvae survival.

- Several natural enemies feed on egg masses and young larvae, including lady beetles, spiders and others.

CORN EARWORM *(Helicoverpa zea)*

Description: Corn earworm larvae vary greatly in colour from light green to yellow. The full-grown larvae are 4 cm (1½ in.) long with prominent stripes running the length of their bodies (Plate 79 on page 292).

> The size and presence of the stripes differentiate earworm from European corn borer, while its tan head colour differentiates it from fall armyworm.

Adult moths are buff or tan coloured. The forewing has a central brown dot visible from the underside of the wing, and the hind wings are pale in colour, with a darker brown border. Egg masses are difficult to see, as they are the same colour and width of a strand of corn silk.

Life History: Corn earworm, also known as cotton bollworm — a pest on cotton, does not over-winter in Ontario but migrates as adult moths from the southern U.S. Usually they arrive in Ontario in August but they may come as early as late June. The moths lay their eggs individually on fresh silks. The eggs hatch, and the larvae feed on the silks and kernels at the ear tip. Larvae will pupate but die soon after frost.

Damage: Larvae may feed on leaves and tassels but mainly are found feeding on silks and developing kernels. Larvae damage tassels, causing poor pollination, and consume silks, affecting ear development. Fields at risk are those planted late that will be freshly silking during peak larvae population time.

> Unlike European corn borer, western bean cutworm and fall armyworm, corn earworm does not leave entry holes into the ear husk as it enters directly via the silk channels. Feeding is concentrated at the top third of the ear tip.

Scouting Technique: Locate five sets of 10 plants per field and open the ear to inspect for feeding damage or larval presence, including the presence of ear moulds carried in by the pest. Determine the percentage of ears infested. Corn earworms are cannibalistic and, therefore, there is usually no more than one larva per ear of corn. Eggs are the same size and colour of a strand of corn silk and therefore are not practical to scout for.

Action Thresholds: This pest is usually only an economic pest in sweet corn but can affect late-planted seed corn fields that are silking at the time of egg-laying.

Management Strategies:

- Earlier-planted corn may have a chance to escape the peak infestations of corn earworm if they silk early enough.
- Insecticides have generally not provided economic control of corn earworm in field corn. There may be some value in treating seed corn to maintain kernel quality.
- Several natural enemies exist in the field, including trichogramma wasps, lady beetles, lacewings and parasitic flies, that help to keep pest populations in check.
- Some transgenic Bt hybrids provide suppression of corn earworm but should not be used for the sole purpose of controlling a sporadic pest such as corn earworm.

FALL ARMYWORM *(Spodoptera frugiperda)*
corn, winter cereals

Description: Full-grown fall armyworms are 4 cm (1½ in.) long, varying in colour from light tan or green to near-black (Plate 80 on page 292). Three white, thin strips run down the back. One thicker, yellow band with red spots runs along the side, just above the legs of the larvae.

> The fall armyworm larvae can be distinguished from the true armyworm by a white, inverted "Y" on the front of the head. The fall armyworm head is dark brown to black. Though the larvae have similar stripes to the true armyworm, fall armyworm larvae also have elevated spots with hair sticking out of each one. Four of these spots form a square on the top of the last abdominal segment of the larvae. Unlike true armyworm, fall armyworm do not have black bands on their prolegs (chubby back legs).

Adults are dark grey moths with a mottled pattern on their wings and a prominent white spot on the very tip.

Life History: Fall armyworm adult moths migrate from the southern U.S. and show up later in the season, when the corn is fully grown. This insect cannot over-winter in areas where the ground freezes.

Damage: Fall armyworm is an occasional pest of grass crops such as corn and wheat. The larvae feed on the whorl leaves and ears predominately from late July to September. Fall armyworm feeding occurs in the daytime, unlike true armyworm feeding, which occurs at night. Initial leaf feeding appears as tiny holes similar to ECB feeding but as the larvae grow, holes become very large, with ragged edges. Moist, reddish-brown frass can be found nearby.

Damage to the ear is similar to that of corn earworm. However, the fall armyworm entry hole can easily be seen coming from the side of the ear, and feeding is throughout the ear. Corn earworm enters the ear through the silk channels, and feeding is typically concentrated close to the tip of the ear.

Scouting Technique: Examine 20 plants from five locations in your field to determine the level of infestation. Record the size and number of larvae. Scout the field perimeters, as armyworm can also move in from neighbouring corn fields.

When scouting, check the backs of armyworms for parasite eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly whose maggots will kill the armyworm larvae.

Action Threshold for Corn: If 50% of the plants are infested with unparasitized larvae smaller than 2.5 cm (1 in.), insecticide treatment may be warranted. However, damage is usually not economical unless infestations are high, and feeding is concentrated on the undeveloped tassels.

Action Threshold for Winter Cereals: Two-to-three unparasitized larvae, less than 2.5 cm (1 in.) in length, per linear foot of row, particularly when the crop is in the younger seedling stages.

Management Strategies in Corn:

- Bt corn hybrids containing Cry1F protein provide some protection against fall armyworm.
- Armyworm tend to move in large numbers from one field to another. When this happens, spray the border of the invaded field. **Chemical control is not effective on larvae larger than 2.5 cm (1 in.) or on those concentrated in the ear.**
- Parasites and other beneficial organisms usually keep armyworms from reaching damaging levels. Avoid treating with insecticides when large numbers of parasitized larvae are present.
- Late-planted corn is most susceptible to leaf and whorl feeding. Grassy areas in and along the field borders are attractive to the egg-laying moths. Therefore, controlling grasses and weeds from the corn field is recommended. Late-season grass control may not be a good option since this will cause the feeding larvae to migrate from the grassy weeds that are now dead to the crop itself.

Management Strategies in Winter Cereals: Fall armyworm populations are rare in winter cereals. If the action threshold is reached, a spray may be necessary.

CORN LEAF APHID *(Rhopalosiphum maidis)*

Description: These aphids are small (2 mm or less), bluish-green, soft-bodied insects with black legs and short black cornicles ("tailpipes") near the rear of the abdomen (Plate 81 on page 292). They have piercing and sucking mouthparts and feed on the juices (nutrients) of young plant tissue (tassel and whorl). They secrete a sticky substance referred to as "honeydew," which can become coated with a blotchy, sooty mould.

Life History: This pest does not over-winter in Ontario but arrives each year on air currents from the south where crops are more advanced. Initial spring migrants feed on cereals, until corn becomes attractive. Migrating populations are comprised of winged females only. Once they settle, these females reproduce without mating and give birth to live wingless nymphs. Both winged and wingless generations of adults develop, depending on the nutrient quality of the plant. Winged aphids then fly to nearby corn fields and enter the whorl. There are several generations per year.

Damage: The degree of feeding injury depends on the size of the population. Nymphs and adults feed primarily on the whorls of the plant, removing nutrients and water. Symptoms include yellowing, wilting and curling of the leaves. During dry periods when the plants are stressed, symptoms may be amplified. As densities increase, leaf surfaces and tassels often become black and sooty as mould begins to grow on the honeydew. Tassels may become gummy, causing poor pollination. They are also vectors of maize dwarf mosaic virus and barley yellow dwarf virus.

Scouting Technique: Examine five sets of 20 plants per field.

Action Thresholds: If 50% of all plants during the late-whorl-to-early tassel stage have 400 aphids per plant, and plants are under moisture stress, control is required.

Management Strategies: Chemical control is warranted only if the natural enemies and parasites of the corn leaf aphids are not present and aphid densities are above threshold. There are several natural enemies that exist and are quite effective at controlling corn leaf aphids. These include lady beetle adults and larvae, lacewing adults and larvae, and a few parasitic wasps.

Chemical control will kill natural enemies and may lead to a resurgence of the aphid population.

Table 13–2. Soybean Insect Symptoms in the Field

	Insects and Pests								
Symptom	**Grubs (June or Japanese Beetles)**	**Seedcorn Maggot**	**Slugs**	**Bean Leaf Beetle**	**Soybean Aphid**	**Japanese Beetle Adults**	**Two-Spotted Spider Mtie**	**Stink Bug**	**Tarnshied Plant Bug**
Gaps in the stand									
Roots pruned, plants wilting, stunted or absent	x								
Tunnelling into cotyledon, embryo or hypocotyl		x	x						
Holes in leaves									
Round holes in leaf				x		x			
Leaves are skeletonized			x			x			
Leaves distorted or discoloured									
Small white stipples on upper surface of leaves, leaves turning yellow							x		
Leaves puckering or plant stunting (leaves may be sticky)					x				
Pod injury									
Pods have holes, feeding scars or are clipped off				x					
Pod is pierced or kinked and seed is dimpled or blemished								x	x

Soybean Insects and Pests

Table 13–2, *Soybean Insect Symptoms in the Field*, this page, shows insects and pests that could be causing the symptoms in the field.

This section describes insects and pests that affect only soybeans. The insects and pests listed below affect soybeans as well as other crops.

Japanese beetle	page 197
June beetle	page 196
Seedcorn maggot	page 199
Slugs	page 199
Tarnished plant bug	page 222

SOYBEAN APHID *(Aphis glycines)*

Description: The soybean aphid is a small (pinhead-size), pale yellow aphid with black cornicles ("tailpipes") and a pale yellow tail (Plate 82 on page 292). Adults may be winged or wingless. Nymphs are smaller than the adults and are wingless. Eggs on buckthorn are small, football-shaped and yellow when first laid but turn a dark brown similar to the colour of the buckthorn branch. Eggs are usually laid along the seams of the buckthorn bud.

Life History: The soybean aphid, a pest originally from Asia, was first discovered in North America in 2000 and in Ontario in 2001. This insect has two hosts that it requires to complete its life cycle. The soybean aphid survives as eggs on the twigs of buckthorn species. In the spring, nymphs hatch from these eggs, and the aphids undergo two generations as wingless females on the buckthorn. The third generation develops into winged adults that migrate to soybean plants. The aphids then continue to produce wingless generations until the soybean plants become crowded with aphids and the plants experience a reduction in quality. Once crowded, winged forms are produced to disperse to less-crowded soybean plants. There can be as many as 18 generations of aphids per year on soybeans. Like most aphids, the soybean aphids are all female, born pregnant and give birth to live nymphs. Males are only born in the fall so that the females and males can mate to produce the egg on buckthorn.

Damage: Aphids have piercing-sucking mouthparts that suck juices and nutrients from the plant. Lower populations of aphids can live and feed on soybeans without causing yield loss. Once populations reach threshold levels, especially in dry years when the plants are stressed, aphids can cause the plants to abort flowers, become stunted, reducing pod and seed production and quality. Yield loss by soybean aphid is greatest when soybeans are in the early R stages (R1–R2), when flowers can abort and impact pod establishment. Peak infestations during the pod fill stage (R3) and beyond can result in smaller seed size and a reduction in seed quality. Aphids also excrete a sticky substance called honeydew, which can act as a substrate for grey sooty mould development. This insect may also be a vector of soybean mosaic virus (see *Soybean Mosaic Virus*, on page 239).

Scouting Technique: Early-season aphid infestations tend to concentrate on the newly emerging leaves and upper trifoliates of the plant. Later in the season, once into the reproductive stages of soybeans, the aphids tend to migrate down to the middle or lower canopy, possibly due to heat and predator abundance experienced at the top of the canopy. Because of this movement within the canopy through the season, taking full plant counts is still the best method to estimate the number of aphids per plant and relate that to the threshold.

Scout each field every 7–10 days from early June until early September or until the crop is well into the R6 stage of soybeans. Scout fields more frequently (every 3–4 days) as aphid populations approach the threshold. Look at 20–30 random plants across the field. Avoid field edges. Estimate the number of aphids per plant in that field. A minimum of two field visits is required to confirm that aphid populations are increasing.

Action Threshold: The threshold for soybean aphids is **250 aphids per plant and actively increasing on 80% of the plants from the R1 up to and including the R5 stage of soybeans**. This threshold gives an approximate 7–10-day lead time before the aphids would reach the economic injury level, where cost of control is equal to yield loss. When soybean aphid populations are not actively increasing above 250 aphids per plant, natural enemies are keeping up with the aphid population. More aphids per plant are needed once soybeans are in the R6 stage. Beyond the R6 stage, economic return from any insecticide application is not likely. Soybean aphid colonies typically start on the underside of the leaves. Once populations begin to increase on the plants, aphids can then be found on the stems and pods of the plant. This is usually a good indication that aphids have reached threshold.

Management Strategy:

- There are several natural enemies, including the lady beetles (ladybugs) (Plates 83 and 84 on page 292), minute pirate bug, syrphid fly larvae and parasitic wasps that are helpful in controlling this pest. A pathogen can also infect the aphids but requires warm, moist conditions to become established.
- When soybean aphid populations are not actively increasing above 250 aphids per plant, natural enemies are keeping up with the aphid population. Do not use an insecticide in this case, as it will kill the natural enemies and enable the aphid population to increase above threshold levels.
- Before applying an insecticide to control aphids, scout for spider mites to ensure that populations are not present. If they are, select the appropriate insecticide that will kill the mites and the aphids, so that the mite population is also controlled and will not flare up shortly after application.

TWO-SPOTTED SPIDER MITE

(Tetranychus uricae)

Description: The adult mite is barely visible to the naked eye, roughly 0.5–1.0 mm (1/25 in.) in length, rounded, eight-legged and yellowish-brown with two dark spots on the sides of the abdomen (Plate 85 on page 293). The larvae look like the nymphs and adults but have six legs instead of eight. Nymphs look similar to the adults, with eight legs. Over-wintering females are orange/red.

Life History: Spider mites generally over-winter as adult females in sheltered areas, such as plant debris and field margins. Harvested wheat fields underseeded to red clover are another important over-wintering site. Red clover provides food for mites until freeze-up, allowing the mites to survive in the field. In late-April, as the weather turns warm, mites become active in search of food and egg-laying sites. Spider mites disperse by crawling, so infestations tend to spread slowly from field edges. Non-mated female mites will mass at the top of the plants and spin webs that serve as a "balloon," allowing strong winds to pick them up and carry them off to another site. Spider mite females can reproduce without mating. A single unmated female can be the start of a new colony. Under hot, dry, windy conditions, infestations can spread very quickly. There can be up to seven generations per year, with generation development overlapping. Frequent rain and cool weather reduce mite populations in soybeans.

Damage: Mites feed on individual plant cell contents on the underside of leaves through stylet-like mouthparts. Each feeding site causes a stipple. Severe stippling causes yellowing, curling and bronzing of the leaves (Plate 86 on page 293). Eventually, the leaf will dry up and fall off. Upon close examination, fine webbing on lower surfaces of the foliage can be seen. Damage is more severe in hot, dry weather and usually occurs in mid-July (after winter wheat harvest). Spider mites usually start at the edges of the field, but windy days can carry them in from other sites, with pockets starting up deeper into the field. From the road, these pockets may have been confused for drought stress. High-risk factors include neighbouring winter wheat stubble fields, hay fields and ditch banks and fencerows that harbour over-wintering mites. No-till fields of soybeans following winter wheat underseeded to red clover are also at risk.

Scouting Technique: Scout fields weekly, starting the first week of July. Infestations tend to occur shortly after wheat harvest and when municipalities mow road sides. Infestations usually move in from the edge of fields as hot spots. Look for tiny white stipples on the upper surface of leaves in the mid-canopy. Pull these leaves from the plant and shake them onto a white piece of paper to see the actual mites moving around. You will need a 10X hand lens to actually see the mites.

Action Threshold: Four or more mites per leaflet or one severely damaged leaf per plant prior to pod fill indicates that control is necessary.

Management Strategies:

- If mite numbers exceed the action threshold, an insecticide may be necessary.
- Use border sprays to keep early infestations under control. This will help prevent the spread of mites to other parts of the field and may reduce the need for further treatment.
- If rain is in the forecast, delay spraying. Prolonged wetness will usually reduce the number of mites to insignificant levels.
- Use of drought-tolerant varieties will minimize the effect of spider mites. Natural enemies help keep mites at low levels when conditions are unfavourable for the mites. Natural enemies of mites include ladybird beetles, thrips and predaceous mites. Cool temperatures and high humidity can promote the development of a pathogen that can provide natural control.

Defoliating Insects

Soybeans are able to compensate for large amounts of foliage loss due to insect feeding, and often little effect on yield is observed. Soybean plants not only continue to put out new leaves at the top to compensate for the feeding but leaves positioned below the feeding injury sites actually grow larger, increasing their surface area, since they are getting more sunlight through the canopy. However, the most critical stage for soybeans is bloom (R1) to pod-fill (R4), when seed development is highly dependent on photosynthesis. Should large amounts of defoliation occur throughout the plant during these stages, yield can be affected, particularly in dry years.

To estimate damage thresholds for leaf-feeding insects on soybeans, determine the percentage of defoliation occurring in each soybean field. In 10 areas of the field, pick trifoliate leaves from five plants in the middle of the canopy. Discard the least and most damaged leaflets from each trifoliate collected.

Compare the leaflets that are left with Figure 13–2, *Defoliation Chart for Soybean Leaf-Feeding Insects*, this page, and determine the average percentage of defoliation. Defoliation is often overestimated. Most of the defoliating insects feed on the tops of the plants and field edges first so that upon first inspection of the field, it appears that there is a lot of defoliation. Make sure to inspect trifoliates from the middle of the canopy to get a good assessment of defoliation.

After determining the level of defoliation in each field, use Table 13–3, *Standard Damage Thresholds for Soybean Insect Defoliation*, opposite page, to determine whether control is necessary, depending on the stage of the crop.

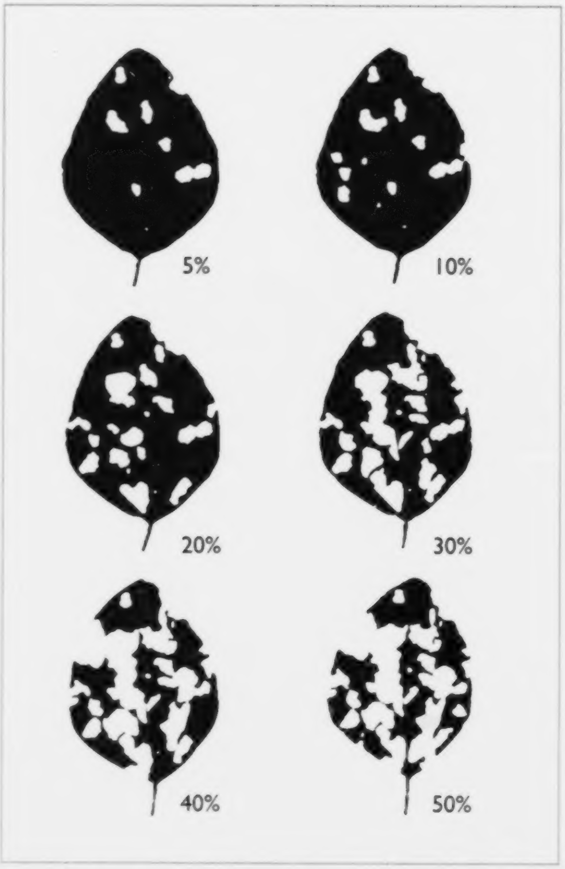


Figure 13–2. Defoliation Chart for Soybean Leaf-Feeding Insects

Source: University of Illinois and Purdue University, 1982.

BEAN LEAF BEETLE *(Certoma trifurcata)* dry edible beans, soybeans

Description: The bean leaf beetle (BLB) adult is around 5 mm (⅕ in.) in length, with or without four black spots (parallelogram shaped) found on the wing covers (Plate 87 on page 293). Adult beetles can vary in colour but are most often yellow-green, tan or red.

A small, black triangle is visible at the base of the wing covers (the prothorax — behind the head). The margins of the wing covers have a black border.

The bean leaf beetle is often confused with the spotted cucumber beetle or lady beetles. A small black triangle is visible at the base of the wing covers (behind the head) of the bean leaf beetle.

Life History: There are two generations of BLB per year, not including the over-wintering population that enters the soybean crop from their over-wintering sites in early spring. The BLB overwinters in the adult stage

Table 13–3. Standard Damage Thresholds for Soybean Insect Defoliation

Soybean Development	% Defoliation
Pre-bloom (i.e., vegetative stages)	30%
Bloom (R1) to pod-fill (R4)	15%
Pod-fill to maturity (R5–R6) (unless pod feeding observed)	25%

in woodlots, leaf litter and soil debris. In late-April, the over-wintering adults become active and begin feeding on nearby alfalfa fields until the first cutting of alfalfa or soybeans emerge. Mated females then lay lemon-shaped, orange-coloured eggs in small clusters in the soil at the base of the soybean plants. Egg-laying occurs until mid-June. There is then a distinct period between the end of June to mid-July when there is little to no adult activity in the field, since most of the population is now in the egg and larval phase. Newly hatched larvae feed on roots and other underground plant parts for about 30 days before pupating. The first generation adults begin to emerge from the soil in mid-July and feed on the soybean foliage and pods. This generation lives for approximately 1 month, laying eggs that will become the second generation adults. A second generation of adults emerges mid- to late August and feeds on the pods until the plants senesce. The adults then migrate to alfalfa fields if available or move to their over-wintering sites.

Damage to Soybeans: Defoliation injury by bean leaf beetle adults is generally not serious in Ontario. The exception is damage caused by over-wintering adults to young soybean plants (V1–V2). Adult feeding appears as small round holes between the major leaflet veins. Cotyledons and seedling plants can be clipped off by heavier populations. Late-season pod feeding is another concern. BLB feed on the surface of the pod, leaving only a thin film of tissue to protect the seeds within the pod. These pod lesions increase the pod's susceptibility to secondary pod diseases such as alternaria. Pods may also be clipped off the plant, but this is not the primary cause of yield loss. The most important concern is that BLB is a vector of bean pod mottle virus. The virus causes the plant and seed to become wrinkled and mottled, reducing the quality of the seed.

Damage to Dry Edible Beans: BLB prefer soybeans, though they can cause injury in dry edible beans, particularily in dry years when populations are high. BLB rarely enter the edible bean crop until mid-season. Defoliation typically does not reach threshold in Ontario. Adult feeding appears as small round holes between the major leaflet veins. Cotyledons and seedling plants can be clipped off by heavier populations. Late-season pod feeding is the main concern in dry edible beans. BLB feed on the surface of the pod, leaving only a thin film of tissue to protect the seeds within the pod. These pod lesions increase the susceptibility to secondary pod diseases such as alternaria. Pods may also be clipped off the plant. However, this is not the primary cause of yield loss.

Scouting Techniques:

Soybean Seedling Stage: Select at least five sampling sites from across the entire field at random. At each sampling site, slowly walk down 4.5–6 m (15–20 ft) of row and carefully count all beetles. Do not disturb the plants, but check closely enough that you can see the underside of the leaves. Calculate the average number of beetles per metre (foot) of row.

Beyond Soybean Seedling Stage: In 10 areas of the field, pick trifoliate leaves that are fully expanded from the centre of the plant canopy from five plants. Discard the least and most damaged leaflets from each trifoliate collected. Determine the percent defoliation that has occurred, using Figure 13–2, *Defoliation Chart for Soybean Leaf-Feeding Insects*, opposite page.

Soybean R5–R6 Stage: Thresholds have not yet been validated for Ontario. Thresholds are based on the percent of pods with feeding damage. Assess pods on 20 plants in five areas of the field. Avoid the field edge. Determine the number of pods with feeding injury or clipping and make note of the presence of adults.

Prior to the Dry Edible Bean Pod-Fill Stages: Determine the level of defoliation taking place. In 10 areas of the field, pick trifoliate leaves that are fully expanded from five plants in the middle of the plant canopy. Discard the least- and most-damaged leaflets from each trifoliate collected. Determine the percent defoliation that has occurred, using Figure 13–2, *Defoliation Chart for Soybean Leaf-Feeding Insects*, opposite page, as a guide.

Dry Edible Bean Pod-Fill Stages: Thresholds are based on the percent of pods with feeding damage. Assess pods on 20 plants in five areas of the field. Avoid the field edge. Determine the number of pods with feeding injury or clipping and make note of the presence of adults.

Damage Thresholds:

Soybean Seedling Stage (VC–V2): Thresholds for bean leaf beetle are 16 adult beetles per foot of row in early seedling stages. If plants are being clipped off, take action.

Soybean V3–R4 Stage: If the defoliation exceeds the thresholds stated in Table 13–3, *Standard Damage Thresholds for Soybean Insect Defoliation*, this page, a rescue treatment may be warranted.

Soybean R5–R6 Stage of IP, Food Grade and Seed Fields: If 10% of the pods on the plants have feeding injury AND the beetles are still active in the field, a spray is warranted. However, remember to consider days-to-harvest intervals.

Japanese beetles can also defoliate soybeans. See *Japanese Beetles* on page 197. For other foliar feeding insects in soybeans, including redheaded flea beetle, corn rootworm adults, grasshoppers, thistle caterpillars and others, follow the same scouting techniques discussed under *Defoliating Insects* and Table 13–3, *Standard Damage Thresholds for Soybean Insect Defoliation*, previous page.

Action Thresholds for Dry Edible Beans: Substantial yield loss does not take place until up to 35% defoliation occurs before bloom and 15% after bloom. Thresholds during pod fill have not been validated in Ontario yet. However, with higher value and stringent quality standards in dry edible beans, if 5%–8% of the pods inspected have feeding scars, control may be necessary. Ensure that adults are still presently active in the field before a spray is applied.

Management Strategies for Soybeans: Plant fields with a history of early-season bean leaf beetle activity and fields planted earliest in the area with insecticide-treated seed. Before applying a foliar insecticide, determine the level of soybean aphid and or spider mite pressure in the field. Certain insecticides can have more impact on the natural enemies than on intended pests and can cause aphid or spider mite populations to flare up.

Management Strategies for Dry Edible Beans: Treat the seeds planted in fields with a history of early-season bean leaf beetle activity or fields planted earliest in the area with insecticide seed treatments. Use foliar insecticides when defoliation thresholds have been reached.

Pod-Piercing Insects

GREEN STINK BUG *(Nezara viridula)*
BROWN STINK BUG *(Euschistus servus)*

Description: There are two types of stink bugs that can injure beans: Southern green stink bugs and brown stink bugs. The Southern green stink bug adults are large (about 1.8 cm (¾ in.) long), light-green, shield-shaped bugs with fully developed wings. Brown stink bugs are smaller than the green stink bug, approximately 1 cm (⅓ in.) in length, and are a mottled brown-grey in colour. Adult stink bugs are shaped like a shield (Plate 88 on page 293). The nymphs (juveniles) can look very different from their adult stage, having very short, stubby wing pads, and are often a different colour than the adults. In particular, green stink bug nymphs have a flashy display of black, green, orange and yellow. Eggs are laid in tight clusters, are yellowish white and barrel-shaped.

Life History: Southern green stink bugs do not over-winter in Ontario but are blown up from the southern U.S. by mid-summer. Brown stink bugs can over-winter in Ontario and may be present in other crops in early summer. Stink bugs are first found in soybean fields during August and early September.

The brown stink bug adult should not be confused with the spined soldier bug, which is a beneficial and feeds on caterpillars and other insect pests. To tell these two apart, look at their feeding beak or needle-like mouthpart. The beak of the brown stink bug is slender to pierce through delicate plant tissue. The beak of the spined soldier bug is thicker so it can harpoon into its insect prey. The soldier bug adult also has more pointed ("spined") shoulders than the brown stink bug, though this may be hard to notice unless you have them side by side to compare.

Damage: Both adults and nymphs have piercing and sucking mouthparts for removing plant fluids. Stink bugs feed directly on pods and seeds. However, their injury is difficult to assess because their mouthparts leave no obvious feeding scars on the outside of the pod. Instead, they inject digestive enzymes into seeds, causing the seed to dimple or shrivel. The feeding wound provides an avenue for diseases to gain entry into the pod. Seed quality is reduced. Indirect effects can include delayed maturity (green bean syndrome) of injured plants, though stink bugs are not the only cause for green bean syndrome.

Scouting Technique: Use the drop-cloth technique in row plantings, and the sweep-net technique for narrow row and drilled beans.

The drop-cloth method involves using a 90 cm (36 in.) long piece of white cloth positioned on the ground between two rows of soybeans. Vigorously shake the plants over the cloth in each of the two rows. Count the number of adults and nymphs and divide the number by 6 to obtain the average number of stink bugs in a 30-cm (1-ft.) row. Repeat this in at least four more areas of the field. Be careful not to disturb the plants prior to shaking them on the cloth.

Using a 38-cm (15-in.) diameter sweep net, take 20 sweep samples (in a 180°-arc sweep) in five areas of the field. Determine the average number of adults and nymphs per sweep by dividing the total count by 100.

Action Threshold: Control may be warranted in IP food grade and seed soybeans if an average of one stink bug per 30 cm (1 ft) of row or 0.2 bugs per sweep is found during the late R5–R6 stages.

Management Strategies:
- Apply foliar insecticide if thresholds are reached.
- Be aware of the preharvest intervals for products.
- Some natural enemies parasitize or feed on stink bug eggs.

Table 13–4. Forage Insect Symptoms in the Field

Symptom	Possible Insect Source						
	Grubs (European Chafer or June Beetle)	Alfalfa Blotch Leafminer	Alfalfa Snout Beetle	Alfalfa Weevil	True Armyworm	Potato Leafhopper	European Skipper
Plants wilting or dying							
Plants dying back or dead, particularly in sandy knolls and first-year fields	x						
Deep spiral grooves in taproot			x				
Feeding injury							
Mines or tunnels between top and bottom layers of leaf		x					
Pinholes or skeletonization of leaves				x			
Leaf-margin feeding, feeding damage to blossoms					x		x
Leaf discolouration							
V-shaped yellowing at leaf tip; leaves appear burned						x	

Forage Insects and Pests

Table 13–4, *Forage Insect Symptoms in the Field*, this page, shows insects and pests that could be causing symptoms in the field.

This section describes insects and pests that affect only forages. The insects and pests listed below affect forages as well as other crops.

European chafer	page 195
Fall armyworm	page 206
June beetle	page 196
Slugs	page 199
True armyworm	page 219

ALFALFA SNOUT BEETLE *(Otiorhynchus ligustici)*

Description: The adult is a flightless, dark-grey weevil approximately 12 mm (½ in.) in length (Plate 89 on page 293). Larvae are small, white and legless with a light-reddish-brown head and can be found in the soil, feeding on or in the roots (Plate 90 on page 293).

Life History: The snout beetle has a 2-year cycle. Adults emerge from their over-wintering sites in April, feed on new alfalfa shoots and migrate into new fields to lay eggs. Adults may walk short distances or may be carried longer distances via the transportation of soil, gravel, hay, farm machinery and waterways. All the adults are female. The eggs soon hatch and begin feeding on the main and side roots of the host plant.

Damage: This potentially serious pest of forage crops was first discovered in Eastern Ontario near Prescott and Brockville. Additional infestations have since been found in Kemptville and Ottawa. The larvae girdle the taproot or gouge its surface, leaving deep spiral grooves. Severely injured plants may appear yellow and leafless in the fall. Adults feed on leaves and stems, causing only marginal damage. Damage is most evident in late summer and early fall.

Scouting Technique: Scout early for signs of beetle migration in infested counties of Eastern Ontario. Later in the season, dig up wilted plants and check them for damage and the presence of larvae. Alfalfa snout beetle has a wide range of hosts. Although it finds alfalfa to be the most attractive crop, larvae of the insect may attack all species of clover, grape and strawberry. They sometimes even feed on weeds, especially ones with fleshy roots such as wild carrot and dandelion.

Action Thresholds: None available.

Management Strategies:

- No chemical control is available.
- Rotation of alfalfa with non-host crops breaks the cycle and decreases the population of snout beetle significantly as long as neighbouring fields are also rotated out of alfalfa during that time.
- Non-host crops include corn, small grain cereals and soybeans. In heavily infested fields, it is recommended that the rotation crops be grown for at least 2 years to reduce the insect population dramatically.
- To minimize the chance of transporting this pest, clean all farm machinery thoroughly before moving it from an infested field.
- Store first-cut hay from infested fields for at least 2 months before it is shipped. There are restrictions on the transportation of hay, straw, soil and compost material from infested fields.

- If this pest is suspected, consult the provincial field crop entomologist, field crop IPM specialist or forage specialist.
- Parasitic nematodes have been found to be effective at collapsing populations in research trials in New York.

ALFALFA BLOTCH LEAFMINER

(Agromyza frontella)

Description: The adult is a very small, black, hump-backed fly. The larvae are small, pale yellow maggots found within tunnels in the leaf tissue.

Life History: In late May, the adult fly emerges from pupa over-wintering on the soil surface. The female adult lays her eggs inside the leaves of new alfalfa plants. The larvae develop inside small tunnels in the leaves. Larvae drop to the ground when mature and pupate. A second generation of adults appear in approximately 1 week (mid-July) and a third generation appears in mid-August.

Damage: This pest of alfalfa is now a more serious problem in Northern Ontario. Small pinhole punctures are left in the leaves when the adult feeds and lays its eggs. The developing maggots feed inside the leaflet, creating tunnels or mines between the top and bottom layers of the leaf. These tunnels usually begin at the base of the leaflet and widen towards the leaf apex, creating a "blotch" appearance (Plate 91 on page 294). Feeding damage primarily decreases forage quality and seldom causes yield loss.

Scouting Technique: Scout fields weekly to determine the percentage of leaves with pinhole feeding.

Action Thresholds: Control is only necessary if more than 40% of leaflets show adult pinhole feeding.

Management Strategies:

- A species of parasite successfully controls the alfalfa blotch leafminer in Southern Ontario.
- Insecticides are harmful to this parasite and, therefore, are not recommended unless leafminer populations are extremely high.
- For insecticides to be effective, apply them no later than the pinhole stage of feeding.

ALFALFA WEEVIL *(Hypera postica)*

Description: The adult weevil is a brown snout beetle, about 5 mm (⅕ in.) long, with a dark brown stripe extending from the head down the centre of the back (Plate 92 on page 294). Larvae are bright green with a black head, six legs and a distinctive white stripe down the centre of the back. At full size, they are about 8 mm (⅓ in.) long (Plate 93 on page 294).

Do not confuse the alfalfa weevil larvae with the clover leaf weevil larvae, which are larger, have a light brown head, not a black head, and a white stripe edged with pink. Also, do not confuse alfalfa weevil larvae with predacious fly larvae, which have no head capsule and are legless.

Life History: Adults over-winter in plant debris and emerge in spring to feed on new alfalfa growth and lay their eggs in alfalfa stems in May. Larvae hatch from eggs and crawl to the tops of alfalfa where they feed on the developing leaf and flower buds. After feeding, larvae form loosely woven white cocoons in leaf masses and enter the pupa stage, usually in late June or early July. Pupae hatch in 1–2 weeks into the adult stage.

Damage: The larvae cause most of the damage as they feed within the leaf buds and then move to the tips of the plant. Damage starts out as pinholes and progress to feeding between the leaf veins, resulting in a skeletonized appearance. In heavy infestations, larvae shred the leaves so badly that fields take on a greyish-white or frosted appearance. Adult feeding throughout the summer does not cause significant damage.

Scouting Technique: Examine each field twice a week from mid-May to June. Check several areas throughout the field. Look for damage to show up first on shallow soils or on southerly slopes, particularly during warm, dry springs. Experience in Ontario has shown that the peak of larval attack usually coincides with the bud stage of the first crop. To count larvae, collect 30 stems in an M-shaped pattern. Place them inside a white pail and beat them against the side to knock off the third-to-fourth-stage instar larvae. First and second instars are smaller (3 mm or less), pale yellow-to-light green, with the white stripe not yet distinguishable. They may be in the upper leaves but do not include these younger larvae in the count. Check to see whether the weevil larvae look active and healthy. Larvae infected by the fungus pathogen are slow-moving, yellow or tan.

Action Threshold:

- Leaf tip damage and weevil counts are used in assessing threshold levels and appropriate action of either cutting or insecticide application. **If there is 40% leaf-tip feeding, with 2 or 3 active weevils per stem, and there is more than 7–10 days to preferred harvest date, consider applying an insecticide.** ("Leaf-tip feeding" refers to the percent of plant tips showing obvious signs of damage, which is not to be confused with the percent defoliation.)
- Less than 1 active larva per stem does not require action, but continue to monitor the situation.
- Two larvae per stem requires action if the alfalfa is less than 40 cm (16 in.) high.

- If there are more than 3 active larvae, immediate action is required.

Occasionally, if weevil populations are high on a late first cut, surviving larvae will feed on the re-growth. Such feeding can eliminate alfalfa re-growth, which may lead to a loss of the stand. With a severe infestation, be sure to monitor stubble re-growth. The characteristic symptom is the alfalfa plant not "greening up," due to weevils feeding on the developing crown buds. **The presence of two or more active larvae per crown, or 4–8 larvae per square foot ($30\ cm^2$) indicates a need to spray the stubble with insecticide.**

Management Strategies:

- Insecticides are recommended only when cutting is impractical, such as when the alfalfa is in the pre-bud stage. Cutting before the bud stage may result in reduced alfalfa vigour and excessive forage quality for most livestock. It can result in reduced yields due to extensive weevil damage to second cut regrowth.
- The key to weevil control is proper timing of harvest or insecticide application based on field inspection. When threatening infestations occur, cut fields immediately to eliminate feeding damage. Most of the larvae will be removed from the field, while any remaining larvae usually dry out, starve and are exposed to natural enemies.
- Occasionally, warm May weather will result in an early hatch of weevil. Feeding damage will show before the bud stage when it would be practical to harvest the alfalfa. In those situations, an insecticide may be warranted.
- Contact local beekeepers so they have an opportunity to move colonies out of the danger area. It should be noted that spraying insecticides on alfalfa will also kill beneficial insects, the natural enemies of alfalfa pests. This increases the potential for future outbreaks of these pests.
- Alfalfa weevil is also controlled by a fungal pathogen, *Zoophthora phythonomi*. Rain and high humidity during periods of peak larval numbers can cause the weevil population to crash quickly. Infected larvae curl around leaves at the tops of plants and then turn brown.

TRUE ARMYWORM *(Pseudaletia unipuncta)*

True armyworm is an important pest of forages. For information on this insect, see page 219.

POTATO LEAFHOPPER *(Empoasca fabae)*
alfalfa, dry edible beans

Description: The potato leafhopper (PLH) adult is a pale green, wedge-shaped, winged insect about 3 mm long with piercing and sucking mouthparts (Plate 94 on page 294). It is most broad towards the head, tapering evenly to the wing tips. It has a row of six rounded, white spots behind the head. Nymphs are smaller than adults and are wingless.

Life History: PLH do not over-winter in Ontario but migrate north every spring, carried by weather fronts that start in the Gulf of Mexico. Adults may arrive in late spring and begin sucking on plant juices. Females lay their eggs in the tissue of main veins and petioles of leaves. Development from egg to adult takes approximately 4 weeks.

Damage to Alfalfa: Damage is most severe in new seedlings and young regrowth. While potato leafhopper nymphs and adults suck juices from plant foliage, they inject a protein that blocks veins. This causes the edges to become yellow and puckered, with a characteristic yellow "V" shape beginning at the tip of the leaves. When severe, the leaves appear burned, which is called "hopperburn" (Plate 95 on page 294). PLH feeding causes reduced stem elongation, reduced root development, leaf cupping and stunting. Yields can be lowered by as much as 50% with a severe infestation, accompanied by a reduction in protein levels of 2%–3%. Decreased stand vigour results in slow regrowth following cutting and increased winterkill. Border areas are usually affected first. The symptoms of potato leafhopper are commonly confused with herbicide injury problems and nutrient deficiency. Most of the damage occurs from June to mid-August. High-risk factors include hot, drier-than-normal seasons. Symptoms are sometimes confused with nutrient deficiency or herbicide injury, and are often dismissed as "drought damage."

Damage to Dry Edible Beans: PLH feed by piercing plant tissue and sucking plant sap. This causes the leaves to curl and pucker, and eventually the leaf edges begin to scorch. These symptoms are called hopperburn. Border rows are affected first. Because yield is lost before hopperburn is evident, do not use the presence of hopperburn as a management guide. Leafhoppers tend to come into soybean and edible bean fields after neighbouring alfalfa fields are cut. The symptoms of potato leafhopper are commonly confused with herbicide injury problems, nutrient deficiency and moisture stress during dry conditions. High risk factors include hot, drier-than-normal seasons.

Scouting Technique for Alfalfa: See *Using Sweep Nets*, on page 177, for a discussion on the use of sweep nets for scouting.

Economic losses occur before plant symptoms develop, so it is important to identify the presence of large leafhopper populations before the damage occurs. It is particularly important to monitor new seedings.

Table 13–5. Action Thresholds For Potato Leafhopper on Alfalfa and Dry Edible Beans

Action Thresholds			
Alfalfa		**Dry Edible Beans**	
Stem Height[3]	**Number of PLHs per Sweep**[1]	**Bean Growth Stage**	**PLH Threshold/ Trifoliate**[2]
9 cm (3.5 in.)	0.2 adults	unifoliate	0.25
15 cm (6 in.)	0.5 adults	2nd trifoliate	0.5
25 cm (10 in.)	1.0 adults or nymph	4th trifoliate	1.0
36 cm (14 in.)	2.0 adults or nymph	first bloom	2.0

[1] 1 sweep = 180° arc.

[2] Adults and nymphs.

[3] The taller the alfalfa, the more leafhoppers can be tolerated before control is necessary.

Scouting with a sweep net will help you determine whether early harvest or spraying is needed. Scout at intervals of 5–7 days, beginning after first cut. Take 20 sweeps from five areas of the field beginning in late June. Avoid field edges. Determine the average number of PLHs per sweep. Next, take 20 alfalfa stems at random and record the average plant height.

Scouting Techniques for Dry Edible Beans: Walk in an "X" pattern. In 10 areas of the field, pick 10 trifoliate leaves that are newly and fully expanded from the centre of the plant canopy. It is important to note that PLH adults readily fly away when disturbed, which makes them difficult to count on excised leaves. Apply a foliar insecticide if a field is near threshold based on counting nymphs, and a number of adult insects are observed in the crop canopy.

Management Strategies for Alfalfa:

- See Table 13–5, *Action Thresholds For Potato Leafhopper on Alfalfa and Dry Edible Beans*, this page.
- Resistant varieties are available that use glandular hairs as the resistance factor. These glandular hairs, both on the leaves and stems, act as mechanical barriers to PLH feeding. The glandular hairs are not fully expressed the first year.
- Treat new seedings of PLH-resistant varieties the same as regular alfalfa.
- When considering whether to use a PLH-resistant variety, include level of PLH infestation expected in a typical year (higher in Lake Erie counties), cost of scouting, insecticide and spraying, any additional cost of PLH-resistant varieties and other performance traits of the variety, such as yield and disease resistance.
- Cutting alfalfa early will potentially reduce egg, nymph and adult populations. A naturally occurring fungal pathogen helps reduce the populations of the PLH under cool, moist conditions.
- Predators and parasites appear to play a minor role in controlling the pest. If populations exceed the action thresholds, an insecticide may be necessary.
- Spraying insecticides on alfalfa will also kill beneficial insects, the natural enemies of PLH, alfalfa weevil and lygus bug.

Management Strategies for Dry Edible Beans:

- See Table 13–5, *Action Thresholds For Potato Leafhopper on Alfalfa and Dry Edible Beans*, this page.
- Research at the Huron Research Station of the University of Guelph has shown insecticide seed treatment to last at least 4–6 weeks after planting, eliminating the need for at least one foliar insecticide application.
- Consider using insecticide seed treatment on fields with a history of leafhopper infestations, to reduce the number of foliar applications required.
- Use foliar insecticides if thresholds have been reached. A naturally occurring fungal pathogen helps reduce the populations of the PLH under cool, moist conditions. Predators and parasites appear to play a minor role in controlling the pest. If spraying during bloom, spray in the evening when bees are less active and contact local beekeepers so they can protect their hives. Rotate insecticide chemical families to reduce the risk of resistance.

EUROPEAN SKIPPER *(Thymelicus lineola)*

Description: European skipper is a sporadic pest of timothy, both in hay and seed production. Larvae can usually be found within rolled leaves where they feed. Younger larvae have black heads that eventually turn brown. Mature larvae are light green, approximately 2.5 cm (1/10 in.)in length and have brown heads with two light bands. The adult is a pumpkin-orange butterfly with a 2.5-cm wing spread that skips about hay fields in midsummer.

Life History: Eggs over-winter on the stems of crop debris and weeds and hatch in the spring. Young larvae roll themselves up in the leaves and seal the leaves closed with silk webbing. Larvae feed on timothy until late-June. The larvae then attach themselves to grass stems or the underside of weed leaves and develop into chrysalids (the pupa stage of the butterfly). In approximately 2 weeks, the adult skipper emerges. There is one generation per year.

Table 13–6. Cereal Insect Symptoms in the Field

Symptom	Possible Insects and Pests										
	Grubs (European Chafer, June Beetle)	Wireworm	Hessian Fly	Cereal Aphid	Slugs	Cereal Leaf Beetle	Armyworm (True)	Wheat Stem Maggot	European Corn Borer	Wheat Stem Sawfly	Armyworm (Fall)
Gaps in the stand	x	x			x						
Seed is hollowed out					x						
Plants stunted or lodges at grain fill. Plants may be bluish-green in colour. Winter wheat mainly.			x								
Bronze patch in field				x							
Leaf feeding											
Scratches running parallel to leaf veins						x					
Leaves are tattered, looking like hail damage					x						
Ragged holes in leaves							x				x
Stem and head issues											
Stem breaks easily from the node, internodes are shortened			x								
Plant breaks and lodges near the base of the plant, tunneling throughout stem, including nodes. Heads are not bleached. Larva found in stem at approx. 1 in. from base of plant.										x	
Head bleached. Caterpillar found within the stem. Eastern Ontario primarily.									x		
Stem easily pulled from plant. Heads bleached while rest of plant still green. Poor grain fill. Maggot may be found within the stem at the top of the plant.								x			
Head clipping							x				

Damage: Larval feeding causes leaf margins to become irregularly notched and when abundant can cause defoliation. When the population is very high, the larvae will also feed on the heads of plants, leaving only the stems remaining in a field. Adult skippers feed on the nectar of flowers and weeds and do not cause any damage to plants.

Scouting Technique: Begin scouting for larvae by late-April. Remove five random, one-square-foot (30 cm^2) samples of forage down to ground level and place them along with the old crop residue into a bag. Tie the bag and leave overnight at room temperature. The caterpillars will crawl out of the residue and can be counted easily.

Action Threshold: Six larvae in a one-square-foot (30 cm^2) area found in the early, brown-headed stage.

Management Strategies: See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations.

Cereal Insects and Pests

Table 13–6, *Cereal Insect Symptoms in the Field*, this page, shows insects and pests that may be causing symptoms in the field.

This section describes insects and pests that affect only cereal crops. The insects and pests listed below affect cereals as well as other crops.

European chafer .... page 195
Fall armyworm .... page 206
June beetle.......................... page 196
Slugs.............................. page 199
Wireworm .... page 198

Cereal Aphid Complex:
BIRD CHERRY-OAT APHID *(Rhopalosiphum padi)*
ENGLISH GRAIN APHID *(Sitobion avenae)*
CORN LEAF APHID *(Rhopalosiphum maidis)*

Description: The bird cherry-oat aphid is the most common aphid found in Ontario cereals. These aphids are small, 2 mm (1/12 in.) or less. Adults are olive-green with patches of red-purple near the rear of the abdomen, between a pair of tubes called cornicles (Plate 96 on page 294). The cornicles and legs are pale green; the antennae are long and black. Younger aphids are light green.

The English grain aphid is typically the largest of the three species and is pale green or light orange with long legs that may appear green to black. They have long black antennae and cornicles.

The corn leaf aphid is also olive green, but the legs, cornicles and antennae are black and the shape of the body is more rectangular, while the bird cherry-oat aphid is bulb-shaped. Similar to all aphids, these species are soft-bodied, winged or wingless, with piercing and sucking mouthparts that suck the juices (nutrients) from young plant tissues. Aphids secrete a sticky substance referred to as "honeydew," which can cause sooty mould.

Life History: Cereal aphids have over-wintered in Ontario, particularly in mild winters with prolonged snow cover. Fields planted in late summer or early fall (August/September) are at highest risk of fall infestations.

Damage: Seldom a direct problem in Ontario. On young plants, aphids cluster on the upper sides of leaves near the base of the plant. Eventually, aphids will climb to the top and can be found in the leaf whorls. High populations can result in fields appearing to have large bronze patches. Cereal aphids are vectors of barley yellow dwarf virus (BYDV). See *Barley Yellow Dwarf Virus*, on page 247.

Scouting Technique: Fall scouting for cereal aphids is important, as early-season infection with BYDV is most harmful to cereals. In spring, scout the field weekly prior to heading. Examine 20 stems in five areas across the field. Shake the plants over a piece of paper and count the number of aphids present or look for colonies specifically at the leaf collar. Also make note of any predators present and whether the aphids are parasitized or infected with a fungus.

Action Thresholds: Prior to the heading stage, 12–15 cereal aphids per stem, and up to 50 aphids per head once headed.

Management Strategies:

- Apply insecticide when the action threshold has been reached. To prevent barley yellow dwarf virus in winter cereals, avoid planting any earlier than 10 days prior to optimum planting date as shown in Figure 4–4, *Optimum Date to Seed Winter Wheat Across Ontario*, on page 93.
- Controlling volunteer wheat 2–3 weeks before planting may help reduce aphid populations in the vicinity of cereal crops.
- Several natural enemies feed on aphids, including lady beetle adults and larvae, syrphid fly larvae and lacewing larvae. Parasitic wasps are also a key natural enemy that can take down aphid populations before treatment is necessary.

HESSIAN FLY *(Mayetiola destructor)*

Description: Adult Hessian flies resemble small mosquitoes. They are smoky grey and fragile, and have pointed abdomens that are a dull red. Adults are weak flyers and only live about 3 days. Larvae are 2 mm (1/12 in.), legless, white maggots. Pupae are reddish-brown, shaped like flax seed and can be found at the base of the plant in late fall and early spring.

Life History: Two generations occur per year. The Hessian fly over-winters as "flax seed" puparia in the base of old plant crowns. Adults emerge in the spring. Rain triggers adult emergence. Females lay their long, reddish eggs in rows like sausage links, on the upper surface of leaves of young winter wheat or volunteer wheat. Larvae develop and feed for approximately 3 weeks before forming a puparium in mid-June. A second generation emerges, and the insect continues its cycle until late September when it forms a puparium for over-wintering.

Damage: Damage can occur in both spring and fall, though it is the fall population that is the main concern, particularly for the winter wheat crop. Other grain crops including barley, oat and rye are considered more tolerant, though infestations may still occur.
Fall injury: Fall plantings may stunt and turn dark-green. Larvae on young plants feed between the leaf sheath at the base of the plant. The enzymes they secrete into the plant cause the stems of the plant to thicken, the plant to stunt and the leaves to broaden. Multiple tillers can develop. Infested plants take on a dark bluish-green appearance. Winter survival of the crop can be impacted.
Spring injury: Spring damage by the first population is concentrated at just above the nodes where the larvae feed. Internodes become shortened, impacting nutrient transport to the head. Stems, when pulled, break easily at infested nodes. Heads can turn white and plants can lodge. High risk fields include susceptible varieties of winter wheat that are planted early, when adults are still flying.

Scouting Technique: In the spring, scout fields when heads begin to fill. Look for plants that have shortened internodes and white heads. Gently tug at the stem of the plant to see if it breaks easily at the node. Look for larvae within the internode where the stem broke off. In the fall, begin scouting 3 weeks after wheat plants have emerged. Examine 20 plants in five locations across the field. Pull away leaves to view the base of the leaf at the stem. Look for the "flax seed" puparia to determine the percentage of infestation.

Action Threshold: None available. Control is based on prevention.

Management Strategies:

- Prevention is the key form of control.
- Delay planting of winter cereals until after the fly-free date will ensure that plants have not emerged until after Hessian adult flies are no longer flying and laying eggs. Fields planted in August/early September are most at risk. See *Planting Dates*, on page 92, for optimum seeding dates for your region.
- Do not plant wheat 2 years in a row in the same field. Destroy volunteer wheat and stubble before planting.
- Resistant varieties are available. No rescue treatments are available.

CEREAL LEAF BEETLE *(Oulema melanopus)*

Description: The cereal leaf beetle (CLB) adult is a metallic, blue-green beetle, approximately 5 mm (⅕ in.) in length, with a reddish-orange head and legs (Plate 98 on page 295). The larvae are 6 mm (¼ in.) in length when mature and yellowish in colour, but this colour is obscured by a black deposit of fecal material making it slug-like in appearance (Plate 97 on page 295).

Life History: CLBs over-winter as adults in leaf litter in sheltered areas such as woodlots and heavy crop debris. These adults emerge in early spring. The mated females then lay their eggs in wheat fields on the upper surface of leaves. The eggs hatch, and larvae are present by mid-May. The larvae will pupate, and adults will emerge by mid-June. Adults feed on wheat briefly and then congregate in corn fields, feeding for a short period before going dormant until fall. In the fall, adults become active again and make their way to their over-wintering sites. There is one generation per year.

Damage: Cereal leaf beetles feed on wheat, oat, corn, forages and grassy weeds. Spring plantings are most attractive, particularly late plantings, though some winter wheat can also be infested in the spring. Both adults and larvae cause damage by chewing long strips of tissue between the leaf veins, leaving the top layer of the leaf intact. This creates a window-paning or "skeletonizing" effect. Most of the injury is caused by the larvae in June. Heavily damaged fields appear silver.

Scouting Technique: Begin scouting in late April. Examine 20 plants in five locations across the field. It is important to scout various areas of the field, as CLB tends to be unevenly distributed across the field. Record the number of beetles and larvae found per plant. Scout every 5 days, as damage can increase dramatically within days.

Action Threshold: One CLB adult or larvae per stem warrants control, especially in the earlier stages of the crop (before heading).

Management Strategies:

- Natural enemies are highly effective at controlling this pest. For the safety of these natural enemies, chemical control is not recommended unless pest population exceeds the action threshold.
- Clean plowing increases the risk of this pest, because the over-wintering sites of the parasites are destroyed.

TRUE ARMYWORM *(Pseudaletia unipuncta)* corn, forages, cereals

Description: True armyworms (also known as common armyworm), when full grown, are 4 cm (1½ in.) long. The dull-green to brown larvae can easily be confused with other caterpillars, including variegated cutworm and fall armyworm. Two distinguishing features of true armyworm are white-bordered stripes running laterally along the body and dark diagonal bands at the top of each abdominal proleg (Plate 69 on page 290). The head is yellow-brown with a network of dark-brown lines creating a mottled pattern. The adult sand-coloured moth has distinctive white spots on the centre of each forewing.

Life History: True armyworms over-winter as partially grown larvae. In early spring, the moths emerge and prefer to lay their eggs in grassy vegetation, including cereals, grassy forages and rye cover crop. Larvae hatch from the eggs and feed at night or on overcast days for approximately a month. There are two generations per year, but it is the first generation that tends to do the most damage to corn in Ontario. Outbreak years tend to coincide with cool wet springs that are detrimental to the parasites that typically control armyworm.

Damage: True armyworm larvae feed at night. Most feeding damage is done on cereals during July. True armyworms do not feed on pure stands of alfalfa but will feed on alfalfa/grass mixtures. In conventional-till corn fields, damage usually occurs first in the border rows, whereas infestations may develop throughout no-till corn following small grains or grass. True armyworm also frequently invades corn fields from neighbouring cereal fields. Larvae strip the leaf margins, moving up the plant to feed on the panicles and flowers leaving only the midrib. As long as the growing point of the plant is not damaged, the corn plant will be able to recover from moderate feeding.

Scouting Technique: The best time to scout for true armyworm is at or shortly after dusk. Examine 20 plants in five areas in the field (100 plants total). During the day, you may find the larvae in the whorl, leaf axil, amongst the crop debris on the soil surface or under soil clods. Also, you may find brown frass, often mistaken for eggs, in the whorl or on the soil near the plant. When scouting, check the backs of armyworms for eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly. The eggs will hatch, and the maggots will kill the armyworm larvae. Record the size and number of larvae. Scout along the field boundaries bordering cereal and corn crops as larvae will "march" in from neighbouring fields and may be controlled prior to entering the corn field.

Action Threshold for Corn, Cereals: For corn past the 6-leaf stage, and cereals at any stage; if 50% of the plants are showing damage and are infested with larvae smaller than 2.5 cm (1 in.), insecticide treatment may be warranted.

As long as the growing point of the plant is not damaged, the corn plant is usually able to recover from moderate feeding. With early-season feeding, insecticide may be warranted in seedling corn if there are two or more unparasitized larvae per seedling and feeding damage exceeds 10%.

Action Threshold for Forages: Control is warranted when five or more larvae (smaller than 2.5 cm) per square foot are found. Avoid treating with insecticides when large numbers of parasitized larvae are present. In seedling crops, two to three larvae (smaller than 2.5 cm) per square foot may warrant control.

Management Strategies:

- If the larvae are over 2.5 cm (1 in.) long, there is no benefit in applying insecticide, since most of the feeding damage has already occurred.
- Treatment may be confined to infested areas. If armyworm are migrating from adjacent cereal or corn fields, spraying an insecticide along the field border may be sufficient.
- Parasites and other beneficial organisms usually keep armyworms from reaching damaging levels, though cool, wet springs are not favourable for these parasites. Avoid treating with insecticides when large numbers of parasitized larvae are present.
- Because grassy, weed-infested corn is attractive to armyworm moths for egg-laying, eliminate weeds from the corn crop and field borders. However, late-season grass control may not be a good option, since this will cause the feeding larvae to migrate from the grassy weeds that are now dead to the crop itself.

FALL ARMYWORM *(Spodoptera frugiperda)*
Fall armyworm is an important pest of forages. For information on this insect, see page 206.

Dry Edible Bean Insects and Pests

Table 13–7, *Dry Edible Bean Insect Symptoms in the Field*, opposite page, shows insects and pests that could be causing the symptoms in the field.

This section describes insects and pests that affect only dry edible bean crops. The insects and pests listed below affect dry edible bean as well as other crops.

Bean leaf beetle	page 210
Potato leafhopper	page 215
Seedcorn maggot	page 199
Western bean cutworm	page 205
Wireworm	page 198

POTATO LEAFHOPPER *(Empoasca fabae)*
Potato leafhopper (PLH) is an important pest of dry edible beans. Information about this pest can be found on page 215.

Defoliating Insects

Research conducted at the Ridgetown Campus of the University of Guelph indicates that prior to flowering, beans are able to tolerate up to 50% leaf loss with minimal loss in final yield. Complete defoliation prior to flowering delayed maturity by 30 days. Lower levels of defoliation did not delay maturity. At later stages, the impact of defoliation is greater. Total losses will be determined by the growing conditions and the ability of the plant to recover. Losing more than one-third of the leaves during flowering or pod fill can greatly reduce yield. See Figure 13–3, *Yield Loss vs. Defoliation of Navy Beans*, opposite page.

Use Figure 13–2, *Defoliation Chart for Soybean Leaf-Feeding Insects*, on page 210, as a guideline to determine if the threshold has been reached.

BEAN LEAF BEETLE *(Certoma trifurcata)*
Bean leaf beetle is an important pest of dry edible beans. Information about this pest can be found on page 210.

MEXICAN BEAN BEETLE *(Epilachna varivestis)*
Description: Mexican bean beetle is the only member of the lady beetle family in Ontario that eats plants. All the other lady beetles are beneficial predacious insects. The adult beetles are oval in shape, approximately 6 mm (¼ in.) in length with 16 small black spots on their coppery-red backs, resembling a lady beetle (Plate 99 on page 295). The heads of the Mexican bean beetle, however, are the same coppery-red colour as their backs,

Table 13–7. Dry Edible Bean Insect Symptoms in the Field

Symptom	Insects and Pests							
	Wireworms	**Seedcorn Maggot**	**Slugs**	**Potato Leafhopper**	**Mexican Bean Beetle**	**Bean Leaf Beetle**	**Western Bean Cutworm**	**Tarnished Plant Bug**
Gaps in the stand: Tunnelling into cotyledon, embryo or hypocotyl	x	x	x[1]					
Holes in leaves								
Ragged holes in leaf (looks like hail damage)			x					
Leaves have been skeletonized					x			
Round holes in leaf						x		
Leaves distorted or discoloured								
Margin of leaves yellow or appear scorched, leaves puckered				x				
Flower blasting or young pod drop								x
Pod/Seed feeding insects								
Holes or scars on the surface of the pods						x		
Entry hole into the pod, holes in the seeds in the pod							x	
Hard dark spots on pods and seed, seeds may have picks or dimples								x

[1] Slime trail noticeable.

whereas lady beetle heads are typically black and white. Adults will darken with age to an orange-brown colour. The larvae are yellow and have 6 rows of long, branching, black-tipped spines along their backs.

Life History: This pest over-winters as adults in grassy fencerows and wooded areas. The adults emerge in May and begin feeding on young bean plants. Eggs are laid on the underside of the bean foliage. Larvae hatch, and young larvae feed in clusters. As they mature, larvae will scatter more. Feeding continues for approximately 1 month before larvae attach themselves to the plant and pupate. Adults emerge approximately 2 weeks later. There are 1–2 generations per year.

Damage: Mexican bean beetle is less of a problem in very hot, dry summers. Early-maturing bean varieties may be grown with little or no injury. Both the adult and larvae feed on the leaves, flowers and pods, but most injury is concentrated on the leaves by the larvae. First symptoms are large holes. As feeding continues, the entire leaf is consumed except for the leaf veins, causing the leaves to look skeletonized. Damage is usually localized.

Scouting Technique: Examine 10 plants at five locations across the field. Monitor border rows. Determine the percentage of defoliation present using Figure 13–2, *Defoliation Chart for Soybean Leaf-Feeding Insects*, on page 210, as a guide.

Action Threshold: Substantial yield loss does not take place until up to 35% defoliation occurs before bloom and 15% after bloom. If border plants show evidence of Mexican bean beetle, a border spray may be necessary.

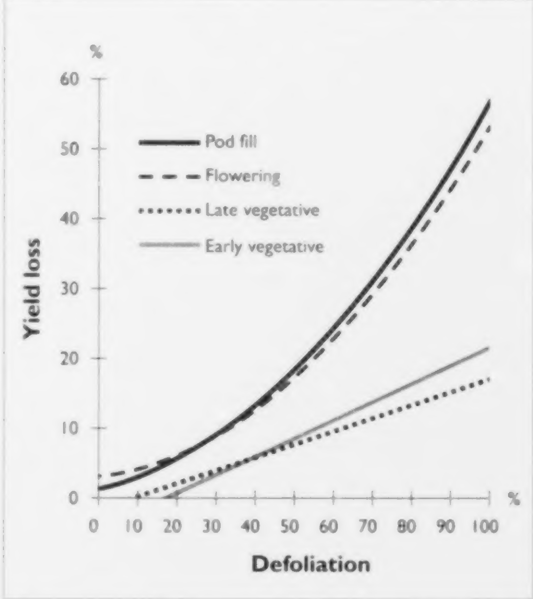


Figure 13–3. Yield Loss vs. Defoliation of Navy Beans
Source: Schaafsma and Ablett, 1994.

Management Strategies: Depending on when the beetles enter the field, insecticide seed treatment may provide some protection against early-season feeding. Foliar insecticide is only recommended if pest populations and damage are at threshold, because insecticide will kill the natural enemies as well. Control weeds along borders and fencerows to expose adults in their over-wintering sites. Several natural enemies keep this pest under action thresholds.

WESTERN BEAN CUTWORM *(Striacosta albicosta)*

Western bean cutworm is an important pest of dry edible beans. Information about this pest can be found on page 205.

TARNISHED PLANT BUG *(Lygus lineolaris)*
dry edible beans, canola, sunflowers

Description: Tarnished plant bug (TPB) adults are approximately 5 mm (⅕ in.) in length, mottled, yellowish-to-reddish-brown in colour and have a small triangle shape on their back (Plate 100 on page 295). The nymph stage does not resemble the adults but can be misidentified as aphids, though they lack the cornicles ("tailpipes") that aphids possess. Nymphs are yellowish-green, wingless and lack the distinctive triangle-shape on their back. Older nymphs develop four small black dots on the thorax and one on the abdomen.

Life History: TPB have several host crops but tend to move into canola and dry edible beans when alfalfa is being cut. They over-winter as adults in the leaf litter and plant debris within fields, woodlots, fencerows and ditch banks. Once temperatures warm up, adults migrate to other host crops to feed and lay eggs. Several generations occur within the summer. It is usually the later generations that enter the edible bean crop once other host crops are no longer suitable for feeding. TPB tend to be more of a prevalent in hot, dry years.

Damage: The adults and later stages of nymphs are the more damaging stages. TPB have piercing-sucking mouthparts that they use to pierce into the plant tissue and inject saliva that breaks down some of the plant tissue. Feeding on flowers can cause flower abortion. Feeding during pod stages results in scarring, malformation and dimpling or pitting of the pods. Sap may ooze from the feeding sites on the pods, which increases the risk of pod disease development. TPB can also drill directly into the seed, causing pick, reducing seed quality. In sunflowers, TPB injury causes kernel brown spot.

Scouting Technique: Monitor fields weekly during the early-pod and seed-filling stages. Monitor intensely after neighbouring alfalfa fields have been cut. Take 20 sweeps in a 180° arc in 5 areas of the field to determine the average number of adults and nymphs per sweep. TPB prefer pigweed in flower, which can be monitored to help indicate when TPB are present in and around the field. Border rows are apt to have higher populations, so ensure that sweeping takes place.

Action Threshold for Dry Edible Beans: A treatment may be required when an average of one to two tarnished plant bugs per sweep is found during the pod stages.

Action Threshold for Canola: No thresholds have been validated for Ontario, though other jurisdictions recommend spraying canola when two tarnished plant bugs per sweep can be found after petal fall, but prior to pod maturity.

Action Threshold for Sunflowers: One tarnished plant bug adult or nymph per nine heads prior to or at bloom warrant control in fields for confectionary production.

Management Strategies:

- Several parasitic wasps help control TPB. Use a foliar insecticide only when threshold has been reached, because insecticides are extremely detrimental to these parasitoids.
- Spray in the very late evening or early morning when bees are less likely to be foraging in the crop. Contact local beekeepers at least 24 hours in advance so that they can move their hives prior to spraying.
- Control weeds, particularly pigweed, which can attract TPB to the field.

Canola Insects and Pests

Table 13–8, *Canola Insect Symptoms in the Field*, opposite page, shows insects and pests that could be causing the symptoms in the field.

This section describes insects and pests that affect only canola crops. The insects and pests listed below affect canola as well as other crops.

Slugs. . . . . page 199
Tarnished plant bug. page 222

CRUCIFER FLEA BEETLE *(Phyllotreta cruciferae)*
STRIPED FLEA BEETLE *(Phyllotreta striolata)*

Description: There are two species of flea beetles that attack canola. The striped flea beetle is approximately 1.5 mm (1⁄20 in.) long and has two cream-coloured stripes along its back. The crucifer flea beetle is bluish-black, 1.5 mm (1⁄20 in.) long and does not have stripes (Plate 101 on page 295). Flea beetles jump when

Table 13–8. Canola Insect Symptoms in the Field

	Insects and Pests					
Symptom	**Slugs**	**Flea Beetles**	**Cabbage Seedpod Weevil**	**Swede Midge**	**Diamondback Moth**	**Tarnished Plant Bug**
Gaps in stand, particularly in patches. Seedlings eaten at or below ground. Cotyledons and leaves chewed.	x	x				
Leaf feeding or distortion						
Pinholes and pits on the leaves. Plants wilting or stunted.		x				
Plants are malformed, not bolting or flowering. Plants that have bolted have a bouquet of pods at injury sites on the plant.				x		
Leaves of young plants have windowpaning or mining scars. Older plants experiencing defoliation in heavy infestation situations. Small green larvae may be present.					x	
Pod- and seed-feeding insects						
Entry hole into the pods. Seeds fed on. Pods may be malformed.			x			
Surface of the pods have pits or scars, particularly in hot dry years.		x				
Small lesions on pods with sap oozing from feeding site. Seeds may be shrunken or shrivelled. Young pods may turn white.						x

disturbed, hence their name. The larvae are white, approximately 3 mm (⅛ in.) in length and have brownish heads.

Life History: The adult beetle over-winters in sheltered areas such as woodlots under leaf litter. In early May, adults emerge and begin feeding on newly emerged canola seedlings. Hot, sunny weather promotes feeding damage. Eggs are laid on or in the soil between May and late June. Young larvae hatch and feed on the roots of the developing crop. Larval feeding occurs for approximately 1 month from June to late July. The larvae then pupate, and adults emerge in early August and feed on canola crops until late October. The adults then locate over-wintering sites. There is one generation per year.

Damage: Both the adults and larvae feed on canola. However, it is the adult stage that is considered to cause damage. Damage is most severe during the initial 3 weeks following plant emergence. Spring adults feed on the leaves of young seedlings, causing a shot-hole appearance. Leaves and plants eventually wilt and die. Stands become thinned, and plants may become stunted. High infestations can cause up to 50% yield reduction. Once the crop reaches the three- to four-leaf stage, the crop can withstand the damage. Late-season adult feeding is usually not a concern (except in winter canola). Hot, dry weather favours this pest. Adults can enter spring canola fields during hot, dry conditions and feed on the surface of the pods, reducing seed development and increasing shatter.

Scouting Technique: Scout newly emerged canola fields every 2 days, especially along border rows, for the migration of over-wintering adults from the fencerows and woodlots. Assess 10 plants in five locations across the field for feeding damage. Determine the average percentage of defoliation occurring. Monitor fields closely for pinhole feeding damage until the plants are past the 4-leaf stage.

Action Threshold: Canola seedlings can withstand up to 25% defoliation in the cotyledon stage under good growing conditions without a significant reduction in yield. Once the crop reaches the 3–4-leaf stage, the plants are generally established and can compensate for the feeding damage. No thresholds are available for late-season pod feeding by the second generation of adults. Only when adult populations are extreme, and dry conditions are hindering the crop from compensating for the pod damage, is a spray recommended.

Management Strategies: Seed treatments containing an insecticide are necessary at planting time to control flea beetles because of the difficulty in predicting their populations. A foliar application of insecticide may still be required should adult activity continue and reach threshold after the seed treatments are no longer effective. Seed treatment insecticides differ in the length of control of flea beetles, so some products should be used in combination with a granular insecticide, which provides longer protection. If damage is isolated along border edges, apply spot treatments. Canola is a valuable foraging crop for honeybees. Avoid applying insecticides during bloom. Removing cruciferous weeds such as mustards along field boundaries will remove alternative food sources.

CABBAGE SEEDPOD WEEVIL
(Ceutorhynchus obstrictus)

Description: The adult cabbage seedpod weevil (CSW) is ash-grey to black in colour and approximately 4 mm (⅙ in.) in length. Like all weevils, it has a snout that resembles an elephant's trunk (Plate 102 on page 295). The larva are white, C-shaped and legless and can be found only within the pod.

Life Cycle: There are two generations per year. In the spring, adults emerge from their over-wintering sites including shelterbelts, leaf litter, fencerows and ditch banks. These newly emerged adults feed on the canola crop and other host plants, including volunteer canola and mustard plants. After mating, the female lays her eggs, typically one per pod, directly into the seedpod itself. The larvae then hatch within approximately 1 week, depending on temperature, and can consume 3–5 seeds during its development. Once mature, the larvae mine out of the pod, drop to the ground and pupate in the soil. Adults emerge from the soil 10 days later to feed on cruciferous plants until it is time to enter their over-wintering sites. The entire life cycle of the insect takes approximately 6–8 weeks. Host plants include the *Brassicaceae* (mustard) family (i.e., canola, broccoli and cauliflower) and cruciferous weeds (e.g., wild mustard, flixweed and stinkweed).

Damage: Cabbage seedpod weevil is a serious pest in winter canola but can also impact early-planted spring canola. Over-wintering adults enter the canola near flowering and may feed on the flower buds, resulting in blasting. Summer-emerging adults can also cause injury by feeding directly on the green pods of later-planted fields. Pod feeding by the larvae can cause up to 35% yield loss. Yield loss is mainly due to the larval feeding injury, either directly from seed feeding or indirectly from premature pod shattering or seed exposure to diseases via the exit holes. Brown seed incidence has also been linked to injury by this pest. Spring canola fields tend to be less attractive, unless they are the only canola field in the area for adults to go to. High-risk fields include the earliest emerging winter canola fields in an area, as well as fields in a spring following a mild winter.

Scouting Technique: Focus scouting on monitoring the adult population. Use a sweep net for sampling to determine population numbers. Begin sweeping when the crop enters the bud stage until after flowering. Take 10 sweeps (in one 180° arc) in 10 locations of the field and determine the average number of adult weevils per sweep.

Action Threshold: No action threshold has been established for Ontario. Winter canola is at such high risk of injury from this pest that control through foliar insecticides is recommended, as long as adults are active in the field. In spring canola, control is not necessary unless at least 2–4 weevils per sweep are found in very early planted fields.

Management Strategies: Research conducted in Ontario by the University of Guelph and OMAFRA indicates the importance of managing CSW in winter canola during early flowering. If budget only allows for 1 application of insecticide, the optimum timing is at mid-flowering, 7–10 days after the first flowers are noticed in the field. If budget allows, the greatest yield protection occurs when two applications of insecticide are made, one at first-flower and a second application 7–10 days later, during mid-flowering. Research did not show a value to spraying in the spring canola crop unless the field was planted very early and thresholds have been reached. Ensure that adults are actively feeding in the field prior to spraying. Spray in the very late evening or early morning when bees are less likely to be foraging in the crop. Contact local beekeepers at least 24 hours in advance so they can move their hives prior to spraying. A parasitic wasp has been found to help control this pest, though insecticide applications will be detrimental to this wasp. Control cruciferous weeds (i.e., mustard, stinkweed) and volunteer canola plants that can act as hosts.

SWEDE MIDGE *(Contarinia nasturtii)*

Description: The adult swede midge is a very tiny light brown fly roughly 1.5–2 mm (¹⁄₁₆ in.). It is difficult to properly identify from other closely related midges. Larvae are small (0.3–3 mm when mature), off-white-to-yellow maggots that congregate at the growing point within the plant.

Life Cycle: This pest has been confirmed to be present throughout Ontario and is now being detected in other states and provinces. There are four overlapping generations per year in Ontario starting in mid-May until October. Swede midge over-winters as a pre-pupa in the soil, and most adults emerge from mid-May to early June. Once mated, the female will lay her eggs on a host crop, typically in clusters of 2–50 eggs on the youngest and most actively growing portions of the plant. Once mature, the larvae fall to the soil to pupate. The pupa can survive in the soil for up to 2 years before emerging as adults. Rain triggers the pupae out of dormancy. Adults are weak fliers and are carried by wind. Pupae may be carried in soil on farm equipment.

Damage: Only spring canola is at risk of injury from this pest, as infestations in winter canola in the fall do not impact yield. Impact in spring canola is strongly dependent on planting date (i.e., crop stage at time of infestation), crop rotation and infestation levels. Late-planted spring canola fields are most at risk. If the plants are infested at a very young crop stage, the canola plants can be extremely stunted and malformed. Enzymes in the saliva of the larvae break down plant tissue. On young plants that have not bolted yet, the larvae feed on the growing point, causing it to deform (Plates 10[illegible] -105, on page 296). The plant becomes stunted, struggles to bolt and produces very few, if any racemes. Without racemes, flower and pod production is impeded. If the canola plant is beyond the bolting stage before the midge enters the plant, the impact is usually not as extreme. Some racemes may become deformed and some pods develop into one cluster or bouquet but still produce seeds and therefore yield. Winter canola fields avoid much of the injury in the spring and summer because they are much more advanced in growth stage than spring canola.

Scouting Technique: Adults can be monitored through the use of pheromone traps. This indicates when adults are flying around and laying eggs. On injured plants, split open the growing point where the malformation of the tissue is located, typically in unexpanded clusters of flower buds. Look for small maggots feeding. This will help confirm that injury is caused by swede midge and not due to herbicide injury application or nutrient deficiency issues.

Action Threshold: No thresholds are available at this time. Control is mainly done through cultural practices.

Management Strategies: Crop rotation and planting date are the most effective methods of control. Plant spring canola fields no later than the first week of June. If fields cannot be planted prior to this date, consider planting a different crop that is not a host to this pest. In fields of known infestations, rotating out of canola and other cruicifer crops for at least 2 or more years, including neighbouring fields within 1 km, will help reduce populations since swede midge are such poor fliers. If these cultural methods cannot be applied to control this pest in fields with a history of damage, apply a foliar insecticide application during bud-stage, just prior to stem elongation to protect the plant from injury so that bolting can still occur. Control all cruciferous weeds that can act as alternative hosts, including mustard, stinkweed and volunteer canola. Clean all farming equipment that is used in infested fields. Leave infested fields until last when working in fields to reduce the risk of spreading the insect to non-infested fields.

DIAMONDBACK MOTH *(Plutella xylostella)*

Description: The adult is a small, light greyish-brown moth approximately 1 cm (½ in.) long (Plate 106 on page 296). It is best identified by the white, diamond-shaped markings along its back when the wings are at rest. The larvae are light green-to-yellowish-green with a brown head and are approximately 8 mm (⅓ in.) long (Plate 107 on page 296). Larvae will wiggle backward when disturbed or drop from the leaves on a silken thread.

Life History: Diamondback moths do not over-winter in Ontario but are carried in on southerly weather fronts in early May. There are three to four generations per year in Ontario. The adult moth typically lays her eggs on cruciferous weeds such as mustard as well as volunteer canola. Larvae hatch within a few days and create mines or tunnels in the leaf tissue. As the larvae develop, they begin to feed on the exterior leaf tissue. Larvae then pupate on the plant in cocoons and adult moths emerge within 2 weeks.

Damage: The main damage is caused by second-generation larvae, when plants are flowering and pod development begins. Young larvae feed on internal leaf tissue on the undersides of the leaf by creating small mines. More mature larvae, when numerous, will feed on the flowers and on the surface of young pods. Damaged pods do not fill correctly. Severe infestations cause the crop to appear white.

Scouting Technique: Examine 10 plants in five locations across the field twice weekly during the growing season. Gently pull out shot-holed plants and shake them on a piece of paper and count the number of larvae present.

Action Threshold: At podding stage of canola, 200–300 larvae/m^2 (approximately two to three larvae per plant). If infestation in the spring occurs very early in a late-planted canola field and the larvae feed on the developing buds, control may be necessary. At the early flowering stage, the action threshold is lower, and control is recommended when populations exceed 100–150/m^2 (one to two larvae per plant).

Management Strategies:

- Rescue treatments are available when populations reach threshold.
- Canola is a valuable foraging crop for honeybees. Avoid applying insecticides during bloom.
- The adult diamondback moth population can be monitored using pheromone traps to warn of a possible infestation.
- Eliminate volunteer canola and cruciferous weeds that act as the initial food source for the spring generation.
- Cool, wet weather reduces moth flight activity, and adult females often die before laying their eggs.
- Humid weather following a rain helps promote the spread of a fungus that kills the larvae. Several predators and parasitic wasps also help control this pest.

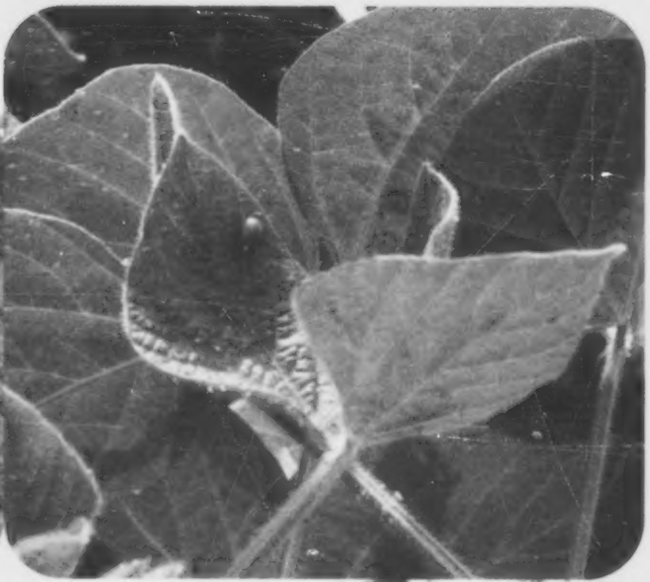
TARNISHED PLANT BUG *(Lygus lineolaris)*
Tarnished plant bug (TPB) is an important pest of canola For information on this insect, see page 222.

Sunflower Insects and Pests

Though rare, a few insect pests have been known to infest fields in Ontario. For confectionary production, yield and quality can be impacted.

SUNFLOWER BEETLE *(Zygogramma exclamationis)*
Sunflower beetles look like smaller Colorado potato beetles. They are approximately 8 mm (⅓ in.) in length with a reddish-brown head, cream-coloured wing covers, with four chocolate-brown stripes running longitudinally along the wings. The fourth stripe at the outside edge of the wing is shaped like an exclamation point. The larvae are yellowish-green in colour, have a humped back and a brown head capsule. Both the adult and larvae feed on the leaves and can be particularly damaging to the seedling crop. Early-planted fields are most at risk. Scout 20 plants in five areas of the field, avoiding the field edges. If one to two adults per plant are found feeding on the seedling crop or 25% defoliation has occurred and the adults or larvae are still actively feeding, control is warranted. Delaying planting can help avoid future infestations.

TARNISHED PLANT BUG *(Lygus lineolaris)*
Tarnished plant bug is an important pest for sunflowers. For information on this insect, see page 222.



14. Diseases of Field Crops

There are many different pathogens responsible for Ontario's common field crop diseases. Their management is an important component in any field crop production system. Scouting and proper disease identification is critical to initiating the correct management practices. The following descriptions will help growers identify and distinguish between the various field crop diseases. Recommended treatments to control insects, pests and diseases and information on integrated pest management options can be found in OMAFRA Publication 812, *Field Crop Protection Guide*, the companion book to this publication, available on the OMAFRA website at www.ontario.ca/crops.

General Seed Rots and Seedling Blights

Incidence: Cool or wet conditions that delay seed germination or seedling development can lead to early-season seed rots, seedling blights and/or root rots. Poor stand establishment, non-uniform emergence, "gaps" or missing plants are obvious signs of seed or seedling infection. There are many different fungal pathogens responsible for these diseases; some infect many crops and others are specific to one crop.

What makes these pathogens difficult to control is their ability to survive in many soil types. Depending on the year and field conditions, their impact ranges from minor to severe (replanting). Low-lying or poorly drained areas of the field are often the first to show disease problems. Seed rots and seedling blights can be more severe in no-till or reduced tillage fields since heavy residue keeps the soil cooler and wetter than in conventionally tilled fields. Damping-off occurs when the crop is planted early into conditions that favour disease development or when environmental conditions cause the seed to sit in the ground for a prolonged period of time. Other factors that delay germination and emergence, such as compaction, crusting or deep planting, can also cause poor stand establishment. It is important to distinguish between seedling diseases and other potential problems, such as insects, herbicide injury and soil compaction.

Appearance: It can be difficult to distinguish between pathogens since symptoms are not always clearly distinguishable. Seed rots are diseases that affect seeds prior to or shortly after germination. With seed rots, seeds decay and die. Seeds that have been damaged or have poor seedling vigour are the most susceptible to seed rots. High risk conditions include cool (10°C–13°C) and wet soil for an extended period of time after planting. Seedlings that take a long time to emerge are most susceptible to fungal infection.

Seedling blights (damping-off) are characterized into two groups, namely pre-emergence and post-emergence seedling blights. Pre-emergence seedling blights affect young seedlings prior to emergence. Affected seedlings may die or grow slower than healthy unaffected seedlings resulting in "gaps" or stand problems. Seedlings that do emerge can also be diseased. Post-emergence seedling blights affect the roots or lower stems of young seedlings from emergence to the second- or third-leaf stage. Symptoms include delayed growth, wilting, dieback and/or death. In most cases, an infected seedling will have a "pinching" or "girdling" of the stem near the soil line.

Organisms that cause root rot infect the seedling's root system, including lateral roots and root hairs. Affected plants may be stunted, off-colour or lack vigour. Infection can result in seedling death when disease infection is severe. Infected plants may be more susceptible to stalk rots later in the season.

Disease Cycle: See the individual crop sections for further details.

Management Strategies: Planting seed with good germination and seed vigour will substantially reduce the risk of seed rots and seedling blights. Remove seeds cracked or damaged during harvest or handling, as they are most prone to infection. Management tactics that favour quick germination, such as minimizing soil compaction, removal of excess soil moisture through improved drainage and removal of excessive crop residues, can also help reduce the severity of root rots and seedling blights.

Fungicidal seed treatments will provide some protection to vulnerable seedlings. It is recommended that all seed be treated with a fungicide seed treatment to minimize early-season pre-emergence and post-emergence disease problems. The average fungicide seed treatment provides up to 2 weeks of protection. There is no replacement for timely planting into a good seedbed.

Corn Diseases

Corn Seedling Diseases

SEED ROT, SEEDLING BLIGHT, ROOT ROT

Incidence and Management Strategies: See *General Seed Rots and Seedling Blights*, previous page.

Disease Cycle: In corn, the most common diseases are caused by *Pythium, Fusarium, Gibberella, Trichoderma* and *Penicillium*, but other fungi such as *Diplodia* and *Rhizoctonia* can also be involved. Seed, seedling and roots infected by *Pythium* are most often soft (wet) and dark coloured, as opposed to roots infected with *Fusarium, Gibberella, Diplodia* and *Rhizoctonia*, which are firm or leathery. The colour of the roots most often provides a good indication of which organism(s) are present:

- greyish-white indicates *Diplodia*
- tan to pink indicates *Fusarium* or *Gibberella*
- reddish to brown indicates *Rhizoctonia*
- blue-green indicates *Penicillium* or *Trichoderma*

Pythium, Fusarium, Gibberella, Diplodia, Rhizoctonia, Penicillium and *Trichoderma* all live and thrive in the soil. In most cases, they can affect other crops besides corn. Except for *Pythium*, all of these organisms also have the ability to live on or in corn seed.

Corn Leaf Diseases

ANTHRACNOSE LEAF BLIGHT
(Colletotrichum graminicola)

Incidence: Anthracnose may become severe in warm, wet years and is often the first corn leaf disease that is noticed. It begins on the lower leaves, working its way up the plant. Symptoms often disappear as the corn plant begins its rapid growth phase. The fungus that causes anthracnose leaf blight is also responsible for anthracnose stalk rot (see *Anthracnose Stalk Rot* on page 231). Record where anthracnose leaf blight symptoms developed early in the season and return to those areas to scout for stalk rots a few weeks before harvest. Tillage systems that leave considerable amounts of anthracnose-infected debris on the soil surface may lead to greater severity of the disease and an increased presence.

Appearance: Anthracnose may affect both leaves and stalks. The main symptoms are leaf spotting, top dieback and stalk rot. Leaf spots are oval, up to 15 mm (6 in.) long, with a tan centre and reddish-brown border (Plate 108 on page 296). Individual lesions may join, forming streaking along the margin or midrib. A general yellowing of the tissue surrounding the infected areas often develops. With the aid of a hand lens, small black spots can be seen in the centre of the lesions. Under close examination, black hairs may be seen protruding from these spots. The disease is first observed on the lower leaves and later on the upper leaves. Top dieback can occur late in the season as diseased leaves wilt and gradually die, taking on the appearance of frost damage.

Disease Cycle: Residue is an important component in anthracnose development, since the fungus survives (overwinters) as mycelium or sclerotia within corn residue or seed. Rain splashes spores from the corn residues onto the lower leaves and stalk. For this reason, second-year corn is the most prone to anthracnose infection, especially when the weather is warm and wet.

Management Strategies: Planting hybrids that are resistant to anthracnose leaf blight can help to manage anthracnose leaf blight. However, resistance to anthracnose stalk rot is separate from resistance to anthracnose leaf blight. Hybrid resistance to anthracnose stalk rot does not guarantee resistance to early-season anthracnose infections on leaves. In conventional tillage corn fields, removal of corn residues through tillage will lower the risk to the disease, especially when corn follows corn. In no-till or reduced tillage fields, management of anthracnose leaf blight is best achieved with rotations (avoiding second-year corn) and planting of resistant corn hybrids. Fungicide applications are not economical in field corn situations, because more than one application is necessary to control the disease. However, in seed corn fields, fungicide applications may be cost effective.

NORTHERN LEAF BLIGHT *(Setosphaeria turcica)*

Incidence: Northern leaf blight has traditionally been one of the most damaging corn leaf diseases. Use of resistant/tolerant hybrids has limited yield losses from this disease in commercial corn. However, in recent years the disease has increased, which may suggest a decline in tolerance levels. Significant losses continue to occur in seed corn production when highly susceptible corn inbreds are planted.

Appearance: The disease appears as long, elliptical, 2–15 cm (1–6 in.), greyish-green or tan streaks. Lesions most often begin on the lower leaves (Plate 109 on page 297). As the disease develops, individual lesions may join, forming large blighted areas. In some cases, the entire leaves may become blighted or "burned" (Plate 110 on page 297). Losses due to northern leaf blight are most severe when the leaves above the ear are infected at or slightly after pollination. The disease is often confused with Stewart's wilt (see *Bacterial Leaf Blight or Stewart's Wilt*, opposite page).

Disease Cycle: The fungus survives in corn residue as either spores or fungal strands (mycelium). The spores of the fungus are spread from the ground residue to the developing corn plant through wind or rain "splashing." Plants that become infected act as a secondary source of infection and may spread to other fields. Disease development is favoured by moderate temperatures (18°C–27°C) with prolonged periods of humid or rainy weather.

Management Strategies: There are various races of northern leaf blight. Most of the commercial corn hybrids have resistance or tolerance to the common races. An increase in northern leaf blight symptoms in an area could indicate the potential for a new race developing and should be reported. Crop rotation and tillage will reduce inoculum levels in surface residues. In reduced tillage systems, rotation and the use of resistant hybrids is necessary. Foliar fungicides are not usually economical in field corn but may be warranted if a susceptible hybrid is planted and disease develops early in the season.

EYESPOT *(Aureobasidium zeae)*

Incidence: Although eyespot normally causes only minor losses in corn, the disease has been increasing in Ontario with the shift to higher corn residues remaining in the field.

Appearance: The disease produces characteristic round or oval spots, 1–4 mm ($^1/_{16}$–$^1/_8$ in.) with a tan/brown centre and a brown or purple margin (Plate 111 on page 297). A translucent yellow halo forms around the margin, and when held to the sun, the lesions resemble an eye. Leaf blighting may occur when these lesions join, killing large portions of leaf tissue. The disease may be confused with non-infectious physiological leaf spots or insect damage.

Disease Cycle: The disease is more prevalent under continuous corn and reduced tillage systems, since the fungus overwinters in corn residue. Disease development is favoured by cool, wet conditions.

Management Strategies: Resistant varieties, crop rotation and clean plowing of crop debris help to reduce disease severity. Foliar fungicides are rarely recommended for the disease.

BACTERIAL LEAF BLIGHT (STEWART'S WILT)

(Pantoea stewartii)

Incidence: Bacterial leaf blight occurs throughout Ontario, but the disease is only of concern in Southwestern Ontario. Essex and Kent Counties, where the majority of seed corn production fields are located, tend to be especially affected by bacterial leaf blight. Warmer-than-normal winters in this area have allowed the corn flea beetle, which is a vector of bacterial leaf blight (Stewart's wilt), to survive in higher numbers.

Appearance: There are two distinct phases of the disease: the wilt phase and the late wilt phase. The wilt phase primarily affects highly susceptible seed corn inbreds and sweet corn hybrids early in the year (V2–V4). The first noticeable sign of the disease appears as long, yellow streaks that extend along the length of the leaf (Plate 112 on page 297). These streaks will take on a water-soaked appearance and eventually become brown, dead streaks. The bacteria interrupt the water and nutrient movement in the plant by plugging the vascular system of the plant. The result is a rapid wilting and even death. Since the new growth is affected, the wilting and death occur from the top down. Cutting the plant lengthwise will reveal a discoloured, rotted or hollowed-out growing point.

The leaf blight phase or late-infection stage often occurs after tasselling and is the most common phase. Symptoms include pale-green to yellow streaks with irregular or wavy margins that run parallel to the veins. These streaks may run the full length of the leaf. Infected leaves eventually become dry and brown. The marks of corn flea beetle feeding are often visible within the lesions. Premature leaf death can result in reduced yield and an increase in stalk rots, since weakened plants are more susceptible to stalk rots.

Disease Cycle: The bacteria overwinters in the gut of adult flea beetles, which hide through the winter in protected areas (see *Corn Flea Beetle,* on page 201). Mild winters can result in higher beetle numbers. Overwintering adult flea beetles feed on corn in the seedling-to-whorl stage, and susceptible varieties will develop a stem wilt, resulting in complete plant loss. This occurs rarely in hybrids but occasionally in susceptible seed corn parents. The next generation of adult beetles emerges after corn silking and causes leaf wilting symptoms, which are commonly seen in many hybrids. Seed transmission is rare. Most often, late infections after silking are associated with high beetle populations. Sweet corn is often more susceptible than field corn and can serve as a reservoir for the bacteria. The disease is often found in the best fields, and fertility seems to play a part. Susceptibility to the disease increases in fields that have high nitrogen and phosphorous levels.

Management Strategies: Field corn has good tolerance to Stewart's wilt and therefore no control is required. Certain seed corn inbreds are susceptible and are rated for disease tolerance. This disease is controlled by managing the corn flea beetle. See *Corn Flea Beetle,* on page 201.

GREY LEAF SPOT *(Cercospora zeae-maydis)*

Incidence: Grey leaf spot is a destructive and economically important disease that has been increasing over the past 10 years in the states surrounding the Great Lakes. Significant losses can occur from this disease under warm, wet and humid conditions.

Appearance: Soon after tasselling, the symptoms develop on the lower leaves. The disease has unique, elongated, 2–7 cm (1–3 in.) long, narrow, light-tan, rectangular lesions. These lesions run parallel to the leaf veins. As the lesions mature, they become grey and join, killing or blighting entire leaves.

Disease Cycle: Grey leaf spot is most problematic when corn follows corn in fields with a considerable amount of corn residue. The fungus survives as fungal strands (mycelium) in corn residue. Spores produced on the residue are dispersed by wind and rain splash. Warm, humid weather favours spore and disease development.

Management Strategies: Crop rotation and tillage will reduce inoculum levels in surface residues. In reduced tillage systems, rotation and use of hybrid resistance may be necessary. Chemical control is not usually needed but if a highly susceptible hybrid is planted and disease development begins early in the season, it may be warranted.

COMMON RUST *(Puccinia sorghi)*

Incidence: Common rust does not overwinter in Ontario. It originates from infected corn in the southern U.S. and Mexico. Rust spores are blown into Ontario. In most years, rust is of minor economic importance. However, sometimes spring storm fronts bring in spores and cause early-season infection. The disease is favoured by high humidity with cool evening temperatures (14°C–18°C), followed by moderate daytime temperatures.

Appearance: Early symptoms of rust infection are yellow flecks or spots on either side of a leaf. These develop into small, brick-red pustules that break through the leaf surface (Plate 113 on page 297). The brick-red colour is the result of spores being released from these oval or elongated 2–10 mm (1–4 in.) lesions. Yellowing of the leaf occurs around these lesions. Dead, brown areas of the leaf develop. In severe cases, the entire leaf dies. The brick-red spores mature and turn black as they mature, causing the lesions and leaf surface to appear black.

Management Strategies: Since common rust does not survive in Ontario, cultural practices such as reduced tillage and crop rotation do not influence disease development. Commercial corn hybrids have good tolerance. However, many seed corn inbreds, sweet corn and specialty corn hybrids are very susceptible to the disease. Foliar fungicides in field corn are not usually needed but can be economical in highly susceptible corn hybrids, seed corn inbreds or specialty corn hybrids.

COMMON SMUT *(Ustilago zeae)*
HEAD SMUT *(Sporisorium holci-sorghi)*

Incidence: Two corn smut diseases, common and head smut, occur in Ontario. Common smut occurs most frequently. In severe cases, over 25% of the plants in some fields can have smut galls.

Appearance: Common smut overwinters in the soil and in corn residue. The spores are spread by wind and rain through splashing. All above-ground plant tissue is susceptible, but infection occurs most often in areas of actively growing tissue. Common smut incidence increases in fields where the plants have been wounded by hail, frost, drought, mechanical injury, detasselling, herbicide injury, insects or sandblasting. High levels of nitrogen and manure promote this disease.

Greyish smut galls up to 10 cm (4 in.) in diameter develop on the stalks, ears and tassels, while smaller galls often appear on the leaves (Plate 114 on page 297). The galls initially have a white membrane cover that eventually breaks and releases dark-brown or black powdery spores. On the leaves, galls develop into a hard, dry growth. Smut galls can replace kernels. Unlike common smut, head smut occurs only on the ears and tassels (Plate 115 on page 298).

Disease Cycle: Spores released from the galls are well adapted for Ontario conditions. They survive in soil and crop residues for many years. In the spring, these spores germinate to produce new spores that will infect the rapidly growing areas or injured areas of the plant. The resulting galls will release spores that infect other plants. Disease development is favoured by rain showers, high humidity and warm temperatures in conjunction with physical plant injury.

Management Strategies: Most commercial corn hybrids have sufficient resistance to smut to prevent serious outbreaks. However, some smut is present in most fields and is still very problematic in many seed corn fields. Risk is reduced by minimizing mechanical and herbicide injury, while maintaining a balanced fertility program. Rotation and cultivation have little effect on the disease, since spores can survive for a long time in the soil.

Stalk Rots

Incidence: Fungi cause corn stalk rots. The amount of damage they cause increases when the crop is under stress, such as prolonged wet or dry conditions, cool temperatures, cloudy weather, leaf diseases (such as rust and Stewart's wilt), leaf and ear damage from hail, birds and frost, incomplete pollination, unbalanced fertility, insect damage (e.g., European corn borer), high plant populations, hybrid susceptibility and poor soil conditions.

The distribution and prevalence of stalk and ear rot diseases vary from year to year. However, the diseases are present in most years even though it may be at low levels. The majority of stalk rot damage in Ontario is caused by three fungi, namely *Anthracnose, Gibberella* and *Fusarium*. However, *Diplodia* and *Pythium* have also been observed in Ontario.

Impact of Stalk Rot: Although these fungi cause different symptoms, their ultimate effect on the corn plant is the same. They reduce grain fill and stalk integrity and accelerate senescence. Stalk rot fungi affect the nutrient movement of the corn plant in three main ways:

- Sugars produced through photosynthesis and carbohydrates in the root and stalk are diverted to the fungus and not to the ear. These nutrients allow stalk rot fungi to grow and flourish.
- There is a reduction in stalk integrity. To meet the nutrient needs of both the developing ear and the stalk rot organisms, the corn plant will begin to cannibalize itself by moving soluble carbohydrates from the root and stalk. Problems arise when the plant is unable to meet the nutrient requirements of the developing ear. The result is a weaker stalk (prone to lodging) and less resistance to stalk rot fungi.
- Finally, the infection and colonization process inhibits or blocks many of the pathways that the plant would ordinarily use to move nutrients. Yield losses (generally 10%–20%) arise from poorly filled ears and harvest losses from lodging.

General Stalk Rot Management Strategies:
Management begins by reducing crop stresses through:

- planting hybrids that have good resistance or tolerance to leaf diseases and stalk rots
- managing insects such as European corn borer
- good weed control
- appropriate plant populations
- a balanced N and K fertility program
- crop rotation
- tillage

Scouting for Stalk Rots

Two methods are used to scout for stalk rots.

The Push Test

1. Randomly select 20 plants from five different areas of the field, for a total of 100 plants.
2. As the name implies, push the top portion of the plant 15 to 20 cm (6 to 8 in.) from the vertical.
3. Note whether the plant lodged or not.

The Pinch or Squeeze Test

1. Randomly select 100 plants in the field (20 plants from five different locations).
2. Remove lower leaves and pinch or squeeze the stalk above the brace roots.
3. Record the number of rotted stalks.

If 10%–15% of plants lodged, or are rotted, harvest the crop early. The extra drying charges that may result will be covered by increased harvest efficiencies with less corn left in the field.

ANTHRACNOSE STALK ROT

(Colletotrichum graminicola)

Appearance: Anthracnose stalk rot is the easiest to identify. It appears as large, dark brown-to-black shiny areas or streaks on the outer stalk rind (Plate 116 on page 298). These shiny or discoloured areas are often found at the base of the stalk. Cutting the stalk lengthwise will reveal a discoloured and rotted pith. Another symptom associated with this disease is "top dieback." Typically, top dieback symptoms begin in late August or early September, as corn plants begin to wilt and die from the top down. This resembles premature death due to frost. Premature death occurs above the ear, with the plant tissue below the ear remaining green. Examination of the stalk in these dead areas will show the same shiny black areas that are found at the stalk base. Plants with top dieback symptoms correspond to areas of the field that had late-season stresses.

Disease Cycle: The fungus that causes anthracnose stalk rot survives in the previous corn crop residues and therefore is most often a problem in second-year corn. Warm, wet and humid weather favours anthracnose development.

GIBBERELLA STALK ROT
(Fusarium graminearum/Gibberella zeae)
FUSARIUM STALK ROT
(Fusarium verticilloides)
DIPLODIA STALK ROT
(Diplodia maydis)

Appearance: These fungi cause general stalk rot symptoms, including wilting and death. Affected leaves turn a grey-green colour that resembles frost damage. All three rots cause a dark external lesion or spots at the lower nodes. Diplodia stalk rot produces small black spots (pycnidia) that are embedded in the stalk rind. These spots are hard to remove. In contrast, gibberella stalk rot also produces small, round, black spots at the lower node, but these spots can be easily scraped from the stalk surface (Plate 117 on page 298). The pith is shredded and has a pink to red colour. Fusarium stalk rot symptoms appear as light-brown to black lesions near the nodes. The internal stalk symptom of fusarium stalk rot is a salmon-pink fungal growth in the pith.

PYTHIUM STALK ROT *(Pythium aphanidermatum)*

Appearance and Disease Cycle: Pythium stalk rot gives the same general above-ground symptoms that are associated with the other stalk rot organisms. *Pythium* is in a unique group of fungi (that also includes *Phytophthora*) called "oomycetes" or "water moulds" because of their preference for wet conditions. The unique characteristic feature of this group of fungi is the production of mobile spores that can move through the water film in saturated soils. These spores (infection stage) are able to physically move to the corn plant roots and, once inside, cause disease. Unlike other stalk rots that produce overwintering structures (black dots) or mould, corn plants infected with *Pythium* have no visible signs of fungal growth at the base of the plant. When the plant is cut lengthwise through the stalk base and roots, *Pythium*-infected tissue will appear wet and soggy and will disintegrate ("a wet rot") at the root base.

Ear Rots or Moulds

Ear Rot Management Strategies: White moulded corn may or may not contain toxins, but pink or purple moulded corn will likely be contaminated. Any of the *Fusarium* or *Gibberella* rots can establish after pollination in wounds created by insects or birds. Warm rainy weather or long dews any time after pollination may lead to ear rots in these wounded cobs.

The green *(Penicillium)* and black *(Cladosporium* or *Alternaria)* moulds do not normally pose a problem. However, when found in great abundance, they may put livestock off feed. Development of ear rots is stopped when corn is dried or ensiled, but the level of harmful toxins already present will remain unchanged. The fungi will continue to produce toxin until corn moisture drops below 20%. More information on *Fusarium* mycotoxicoses can be found on the OMAFRA website at www.ontario.ca/crops.

Preventing ear rots and mould is difficult since weather conditions are critical to disease development. Although some tolerant hybrids are available, none have complete resistance. Crop rotation can reduce the incidence of diplodia ear rot. Cultural practices have been shown to have limited success in preventing ear and kernel rots. Minimize these diseases through timely harvest and proper drying and storage.

Harvest fields where 10% of the ears have some ear rot quickly to limit further disease development and potential mycotoxins production.

When ear rot is present, the following harvest, storage and feeding precautions are advisable:

- Harvest as early as possible.
- If bird damage is evident, harvest outside damaged rows separately. Keep and handle the grain from these rows separately.
- Adjust harvest equipment to minimize damage to corn. Clean corn thoroughly to remove pieces of cob, small kernels and red dog.
- Cool the grain after drying.
- Clean bins before storing new grain.
- Check stored grain often for temperature, wet spots, insects and mould growth.
- Control storage insects.
- Exercise caution in feeding mouldy corn to livestock, especially to hogs. Pink or reddish moulds are particularly harmful. Test suspect samples for toxins.

See Appendix D, *Feed- Mould- and Mycotoxin-Testing Laboratories*, on page 261, for a list of laboratories.

FUSARIUM EAR ROT *(Fusarium verticilloides)*

Incidence: Fusarium ear rot is common in Ontario. Unlike gibberella ear rot, kernels infected with fusarium ear rot will be scattered around the cob among healthy-looking kernels or on kernels that have been damaged (by corn borer or bird feeding). Silks are susceptible to infection during the first 5 days after initiation.

Appearance: *Fusarium* infection produces a white-to-pink or salmon-coloured mould (Plate 118 on page 298). A "white streaking" or "star-bursting" can be seen on the infected kernel surface. Although many *Fusarium* species may be responsible for these symptoms, of concern in Ontario is *Fusarium verticilloides*.

Disease Cycle: *Fusarium* survives in corn debris. The significance of this fungus is that it produces a toxin called fumonisin that has been shown to cause cancer in humans. The environmental conditions that favour disease development are warm, wet weather, 2–3 weeks after silking.

GIBBERELLA EAR ROT *(Fusarium graminearum, Gibberella zeae)*

Incidence: The most common and important ear mould in Ontario is *Gibberella zeae*, which is the sexual reproductive stage of *Fusarium graminearum*. This fungus not only infects corn but also small grains such as wheat. Many plant pathologists believe that in years with a high occurrence of fusarium head blight in wheat, the potential exists for increased gibberella ear rot in corn.

Appearance: Although, the fungus can produce a white mould that makes it difficult to distinguish from fusarium ear rot, the two can be distinguished easily when *Gibberella* produces its characteristic red or dark-pink (purple) mould (Plate 119 on page 298).

Disease Cycle: Infection begins through the silk channel. Therefore, in most cases, it starts at the ear tip and works its way down the ear. In severe cases, most of the ear may be covered with mould growth. Corn silks are most susceptible 2–10 days after initiation. Cool and wet weather during this period is ideal for infection.

Caution: In addition to its economic importance due to yield loss, gibberella ear rot is also important because *Gibberella zeae* and *Fusarium graminearum* produce two very important mycotoxins — deoxynivalenol (vomitoxin or DON) and zearalenone. These mycotoxins are especially important to swine and other livestock producers since they can have a detrimental effect on the animals. Feed containing low levels of vomitoxin (1 ppm) can result in poor weight gain and feed refusal in swine. Zearalenone is an estrogen and causes reproductive problems, such as infertility and abortion in livestock, especially swine. Test feed grain that originates in a field with 5% or more gibberella ear rot for these toxins. See Appendix D, *Feed- Mould- and Mycotoxin-Testing Laboratories*, on page 261.

DIPLODIA EAR ROT *(Diplodia maydis)*

Incidence: Of the three primary ear rots that occur in Ontario, diplodia ear rot is the least common. Diplodia ear rot is caused by *Diplodia maydis* and is favoured by cool, wet conditions through grain fill.

Appearance: The characteristic ear symptom is a white mould that begins at the base of the ear and eventually covers and rots the entire ear. Mould growth can also occur on the outer husk, which has small black bumps embedded in the mould. These reproductive structures are where new spores are produced. Diplodia ear rot does not produce any known toxins.

Disease Cycle: Diplodia ear rot overwinters in corn debris left on the soil surface from the previous crop. Spores that are produced during wet weather can infect silks and husks or enter through tissue damaged by birds or insects. Disease development is favoured when cool wet weather occurs during the first 21 days after silking.

Soybean Diseases

Seedling Diseases

SEED ROT, SEEDLING BLIGHT, ROOT ROT

Incidence and Management Strategies: See *General Seed Rots and Seedling Blights*, on page 227.

Disease Cycle: In Ontario, five fungi are most often associated with early-season emergence problems in soybeans. These include *Pythium* and *Phytophthora* (called "water moulds"), *Phomopsis, Fusarium* and *Rhizoctonia*. Typical "damping-off" symptoms can be caused by one or more of these organisms. Although these organisms can be seed-borne, they are present in most fields to some degree. Seedling diseases are prevalent under cool wet conditions that keep the soil temperatures below 13°C. These organisms often survive as saprophytes, living on dead plant material, or as dormant mycelium or spores. Root exudates from germinating seedlings or growing roots stimulate the inactive fungi.

Lesions that appear water-soaked with brown or purple roots or lower stems are often the result of infection by *Pythium, Phomopsis* or *Phytophthora*. A reddish or brown lesion near the soil line is characteristic of *Rhizoctonia* or *Fusarium* (Plate 120 on page 298), respectively. Growth and vigour are often reduced in those plants that do survive.

PHYTOPHTHORA ROOT ROT *(Phytophthora sojae)*

Incidence: Phytophthora root rot is a potential problem in heavy clay soils. It remains one of the most destructive diseases of soybeans in Ontario. In problem fields, increased frequency of soybeans in the rotation increases the disease pressure.

Appearance: The disease can affect soybeans at any stage of development but is often most damaging when it occurs early in the season. Plants infected at the primary leaf stage display typical "damping-off" disease symptoms. Seeds may fail to emerge, or infected seedlings are killed shortly after emergence. Infected areas of the stem are water-soaked or "bruised" and disintegrate easily (soft rot) (Plate 121 on page 299). Since it causes a "wet rot," it is difficult to distinguish phytophthora root rot from pythium root rot at this stage. Both diseases cause taproot and lateral root pruning or rotting, resulting in yellowing of the leaves, wilting and even death. Infected plants are easily pulled from the ground, since the plants are not well anchored. Older plants can be affected any time before maturity. A purple or dark-brown discolouration of the stem may extend from the roots (just below the soil line) to the lower nodes of wilted plants. Dead plants may appear a few in a row or as patches in low areas of fields. Leaves will often remain attached to the plant even after death.

Disease Cycle: Cool, wet weather favours disease development. Low, poorly drained areas and slow-drying areas of the field are most prone to the disease. Heavy clay soils, reduced tillage and monoculture of soybeans may increase the damage due to the disease. *Phytophthora* and *Pythium* are unique organisms, in that they produce mobile spores that can swim in the water film between soil particles to locate soybean roots. The fungus colonizes the root tissue and will plug the water-conducting tissues of the plant, resulting in wilting of the plant.

Management Strategies: Control of phytophthora root rot requires a combination of:

- soybean variety selection
- seed treatment
- good soil management

Soybean varieties with resistance or tolerance to phytophthora root rot are available. Some varieties have both resistance and tolerance. For variety profiles, consult soybean seed company reps, or the Ontario Soybean Performance Trials, available on the Ontario Soybean Growers website at www.soybean.on.ca.

Resistant varieties. The *Phytophthora* fungus is present in soils as a series of races. Resistance in any one soybean variety is effective against some but not all of the races. Root rot is controlled in a particular field when the variety grown is resistant to all of the *Phytophthora* races that happen to be present in that field. However, resistance will "break down" with the appearance of another race, to which the variety is not resistant. If this occurs, switch to a variety that is resistant to the new race or use a tolerant variety or a different gene for resistance. Grow varieties with different resistance genes in rotation. To determine which races may be present in a field, plant strips of several varieties with known race resistance.

Tolerant varieties. Some disease develops in these varieties when grown in infested soils regardless of which races of *Phytophthora* are present. Yields of tolerant varieties are not usually seriously reduced by the disease, but plants are not immune. Therefore, under extremely favourable conditions for disease development, plant injury can occur.

Any soil management practice that reduces soil compaction or waterlogging will decrease the incidence of phytophthora root rot. On clay soils where the disease may be a problem, the following procedures are recommended:

- Choose a variety with a low percentage of infected plants (field tolerance) and a good resistance gene (Rps1c, Rps1k or Rps 8). See the *Ontario Soybean Variety Performance Trial Report* on the Ontario Soybean Growers website (www.soybean.on.ca).
- Rotate with corn and wheat. A short rotation will result in a higher population and an increase in the number of races present in the field.
- Do not work the field when the soil is wet.
- Use good soil management practices to improve soil structure and drainage (rotation, manure, cover crops, reduced tillage, etc.).
- Tile inherently slow-draining fields.
- A small amount of tillage will help warm soil and increase surface drainage.
- Plant when soil temperatures are above 13°C.
- Inspect each soybean field for dead plants in late July or early August to determine whether the variety has enough resistance/tolerance to provide adequate protection under local conditions.

RHIZOCTONIA ROOT ROT *(Rhizoctonia solani)*

Incidence: Rhizoctonia root rot has been found in most of the soybean-growing areas of the province. In most fields, stand losses range from less than 5% to over 50% in severe cases. The disease has been increasing in importance and can result in substantial yield losses. It is most prevalent on seedling and young plants, causing a root and stem rot, particularly during prolonged wet periods.

Appearance: Rhizoctonia root rot causes pre-emergence (seed rot) and post-emergence (seedling blight) damping-off on affected seedlings. A characteristic reddish lesion is produced on the stem at or just below the soil line (Plate 122 on page 299). These firm, dry, brick-red lesions can join, forming a sunken girdling of the stem that may move down the taproot, pruning roots along the way. Above-ground plant symptoms are very similar to plants infected with phytophthora root rot. Affected plants are pale yellow, which is often confused with nitrogen deficiency symptoms or poor nodulation. Severely infected plants may lose their leaves. Wilted and/or dead plants often occur in small patches. Stem lesions girdle the stem and weaken the plant, often causing infected plants to break at the soil line under stormy conditions. Stressful growing conditions favour this disease. Rhizoctonia root rot is most damaging when cool, wet conditions in the spring are followed by hot (25°C–29°C), dry conditions.

Disease Cycle: This disease occurs on all soil types and environmental conditions. The fungus is primarily a soil inhabitant and survives as resting mycelium or sclerotia. Disease severity will be greatest in fields that have a history of the disease. Over time, small infected areas increase in size.

Management Strategies: Few management options exist since no resistant and few tolerant varieties are presently available. Crop rotation with corn and small grains can help minimize the disease. Maintain good soil drainage and avoid planting under cool, wet conditions. Fungicide seed treatments offer some measure of protection and increase emergence.

Leaf and Stem Diseases

SEPTORIA BROWN SPOT *(Septoria glycines)*

Septoria brown spot is a fungal disease that normally does not cause major yield losses in Ontario. However, losses of 5%–10% have been observed in the province in very susceptible varieties that have been infected early and have been under prolonged stress conditions.

Appearance: Symptoms first appear on the primary unifoliate leaves shortly after trifoliolate leaves have developed. Disease symptoms begin as small, dark brown, irregular spots (1–2 mm (1/16 in.) in diameter) with or without a yellow halo, which develop on upper and lower surfaces of lower leaves. Lesions may enlarge and coalesce, and frequently they are concentrated along the leaf veins or at the leaf margin (Plate 123 on page 299). Rapid yellowing and senescence (death) of infected leaves occurs. Symptoms may be difficult to distinguish from those of bacterial blight, soybean rust and downy mildew. One way of distinguishing the disease is that characteristic brown pycnidia (spots) are imbedded in the dead tissue of older lesions.

Disease Cycle: The fungus does over-winter on crop debris and can be spread by infected seed. In most cases, seed infection is low in commercial seed. It can be a problem in seed that has not been cleaned or has been kept for a number of years. Initial infections on primary leaves and cotyledons produce secondary inoculum that infects upper leaves as they develop. Humidity and moisture are important for brown spot development and spread (through splashing). The fungus produces a toxin that contributes to yellowing.

Management Strategies: The disease is more cosmetic than damaging, but development early in the season can lead to significant defoliation of the plants. There are differences in soybean varieties, but none are completely resistant. A good rotation with non-host crops, such as wheat and corn, will lower disease levels. Fungicides are not normally economical.

SOYBEAN CYST NEMATODE *(Heterodera glycines)*

Incidence: Since it was first identified in Ontario in 1988, soybean cyst nematode (SCN) has been identified in most counties west of Toronto and more recently in parts of Eastern Ontario.

The disease can be managed effectively, but the first step is identification and awareness. Losses to SCN in Ontario have ranged from 5%–100%. Unfortunately, by the time SCN symptoms become visible on the plants, the producer has lost significant yield potential. Once SCN is in a field, eradication is impossible.

Appearance: These microscopic, worm-like nematodes damage the root system and prevent the uptake of water and nutrients. In many cases, SCN symptoms may not be obvious in a field until populations build significantly. At this point, typical above-ground SCN symptoms include yellowing of the leaves, stunting of plants and early maturity, particularly on lighter soils under dry conditions (Plate 124 on page 299). Damage often occurs in circles and is often confused or misdiagnosed as nutrient deficiency, flooding, herbicide injury, compaction, drought or root rot damage. Yellowing of the leaf margins can resemble potassium deficiency symptoms. However, the addition of potassium will not reduce the damage from SCN or eliminate symptoms. Never pull up a plant to check for SCN since too much root will be lost, and the nematodes will be stripped off. Instead, use a shovel and dig up the plant along with the soil surrounding the roots.

Below-ground SCN symptoms include dwarfed, stunted and discoloured roots (due to root rot pathogens) with few nitrogen-fixing nodules. However, the most obvious sign of SCN infection is the presence of the adult female "cysts" on the roots — white to yellow-brown cysts less than 1 mm in diameter (pin-head) (Plate 125 on page 299). Nematode injury symptoms (including plant death) are most obvious under stressed growing conditions, especially hot, dry environments. Under good growing conditions, the visual damage from soybean cyst nematode may go unnoticed. In contrast, under high-stress conditions, even low SCN numbers cause considerable visual damage and high yield loss.

SCN infection symptoms may not be obvious and yield reductions of 25%–30% on susceptible fields can occur without visual (above-ground) symptoms. Areas of the field where above-ground SCN symptoms will most often occur include entrance points for equipment into the field, equipment and vehicle storage areas, tops of knolls, compacted headlands and along the fencerow where wind-blown soil tends to accumulate.

Disease Cycle: The life cycle of SCN has three major stages: egg, juvenile and adult. The cycle begins when eggs hatch to release worm-shaped juveniles in the soil. This is the only stage when SCN can infect soybean roots. Once they have penetrated the roots, the young nematodes migrate to the water and nutrient-conducting tissue (vascular system) and establish a feeding site. At this stage, the female nematode begins to swell and eventually breaks through the root surface. Adult females that remain attached to the root to feed produce eggs in a mass, or egg sac, outside of the body. As the life cycle nears completion, eggs also develop within the female's body cavity, called a "cyst." Initially white, the cysts turn yellow and brown as females mature. Each cyst can contain 100–300 eggs. The number of cysts per plant varies from a few to many hundreds. In infected soil, cysts are distributed throughout the root zone and can survive for 10 or more years. The entire life cycle takes approximately 4 weeks when soil temperatures are 25°C.

Management Strategies: The following practices will decrease the likelihood of this pest causing significant economic losses:

- Plant certified or good-quality, clean seed that is free of soil peds.
- Wash soil off farm equipment when moving it between infested fields or farms.
- Use proper soil conservation practices to reduce soil movement between fields.
- Practice prudent weed control. Many weeds, particularly annual weeds such as purple deadnettle, henbit and field pennycress, may serve as hosts to SCN.
- If SCN has been diagnosed in a field, use SCN-resistant soybean varieties. SCN will significantly reduce yields. Therefore, when selecting soybean varieties for fields with a history of SCN, ensure that the variety has SCN resistance (PI 88788, Peking, PI 437654). This is especially true for new technologies or traits such as herbicide resistance.

Table 14–1. Potential Risk of Yield Loss for Various SCN Population Levels
(based on soil test results)

SCN population (eggs per 100 gm of soil)	Risk Rating	Potential Yield Loss	Rotation
0–500 (coarse, sandy soils)	Low risk	0%–20%	4 year
0–1,000 (fine-textured silt or clay)	Low risk	0%–20%	4 year
1,000 (coarse, sandy soils)	High risk	20%–50%	6 year
2,000 (fine-textured silt or clay)	High risk	20%–50%	6 year
10,000 (all soil types)	Resistant variety may be damaged	50%–100%	non-host

Source: Welacky, Anderson and Tenuta. Agriculture and Agri-Food Canada and OMAFRA, 2000.

- SCN resistance is not 100% effective, and a few cysts can be found on the roots. The better the resistant variety and the less diverse the SCN field population, the fewer cysts on the roots. Avoid continuous use of the same resistant variety since it will pressure the SCN population to adapt and shift in the field, thereby making the variety ineffective in combating this pest. Consult the *Ontario Soybean Variety Performance Trial Report* for SCN-resistant varieties, resistance genes and their performance on infested soil.
- Establish a rotation with non-host crops such as corn, wheat, alfalfa, oat, clover, vegetable crops, such as tomatoes and some cover crops (see *Cover Crops*, on page 146) which benefit by reducing SCN populations and improving yields. It is not advisable to substitute dry edible beans into the rotation instead of soybeans since these crops are also hosts for SCN. See Table 14–1, *Potential Risk of Yield Loss for Various SCN Population Levels*, this page.
- Monitor SCN population in the soil by soil sampling every 3–6 years. Send samples for nematode analysis to any of the laboratories listed in Appendix E, *Soybean Cyst Nematode-Testing Laboratories*, on page 262. Ask for both an egg count and a total cyst count.

POWDERY MILDEW *(Microsphaera diffusa)*
DOWNY MILDEW *(Peronospora manshurica)*

Incidence: Both diseases are most noticeable when conditions are wet or humid. Although powdery mildew and downy mildew occur in most fields, they are considered minor diseases and economically insignificant.

Table 14–2. Symptom Expression on Roots, Stems and Leaves for Brown Stem Rot, Stem Canker and Sudden Death Syndrome on Soybeans

Plant Part	Brown Stem Rot	Stem Canker	Sudden Death Syndrome
Roots	• healthy	• healthy	• root rot • browning of roots • internal browning of tap root
Exterior stem	• healthy	• dark, reddish-brown sunken canker starting at node • canker may extend length of stem • often on one side	• healthy
Interior stem	• brown pith (centre) • white tissue below stem surface	• begins with slight browning at nodes • severely diseased stems completely deteriorated	• white, healthy pith • browning of tissue below stem surface
Leaves	• wilting of upper leaves • yellow spots between veins • increase in size until all tissue between veins is yellow, then brown • leaves remain attached to plant	• general yellowing of leaves • no distinct yellow spots or blotches • interveinal yellowing can lead to necrosis or dead tissue	• wilting of upper leaves • yellow spots between veins • increase in size until all tissue between veins is yellow, then brown • leaves remain attached to plant

Appearance: Powdery mildew appears as a white powdery growth of the mildew fungus on the upper surface of the leaf (Plate 126 on page 299). The soybean seeds do not become infected.

Downy mildew appears as yellow-to-brown spots on the leaves during late July through September (Plate 127 on page 300). In moist weather, a pale blue-to-grey, downy growth of the mildew fungus appears on the lower leaf surface, directly under these spots. Severely affected leaves may drop prematurely. Whitish growth of the fungus may encrust the seeds, affecting even healthy pods. Planting infected seed may result in diseased seedlings.

Disease Cycle: Powdery mildew develops on the leaves, usually in August and September. Outbreaks arise when disease symptoms begin in early July and the environmental conditions remain cool, cloudy and humid through to pod fill. Downy mildew survives in infected leaves and on seed. Air-borne spores blown into Ontario from the U.S. are the most common cause of infection.

Management Strategies: Removal of crop residue and rotation with non-host crops, such as corn and wheat, will help prevent both diseases. Fungicidal seed treatments will reduce seed-borne downy mildew.

BROWN STEM ROT *(Phialophora gregata)*
STEM CANKER *(Diaporthe phaseolorum)*
SUDDEN DEATH SYNDROME *(Fusarium verguliforme)*

Incidence: All three diseases are found in all soybean-growing areas of Ontario but are more common in southwestern counties. Yield losses range from a few bushels to significant portions of the field being killed (especially for sudden death syndrome).

Appearance: To aid in correctly identifying these diseases, see Table 14–2, *Symptom Expression on Roots, Stems and Leaves for Brown Stem Rot, Stem Canker and Sudden Death Syndrome on Soybeans*, this page.

Brown Stem Rot (BSR): Symptoms of the disease generally develop in August during pod fill. Upper leaves develop yellow and necrotic areas between the veins similar to sudden death syndrome. Plants wilt suddenly, and pods are poorly filled. The disease is more prevalent under minimum tillage.

Stem Canker: This disease may cause seedling damping off and wilt but commonly affects soybean plants after flowering. Plants wilt suddenly, and leaves and petioles droop, resembling symptoms of phytophthora root rot. Brownish-red lesions appear on the exterior of diseased plants at lower nodes (Plate 128 on page 300). The pith of diseased plants is generally brown near the nodes. The fungus can also cause a stem or tip dieback late in the growing season. The fungus can cause seed mould similar to phomopsis seed mould. Stem canker overwinters in crop debris and is more prevalent in minimum tillage situations.

Sudden Death Syndrome (SDS): Infected plants wilt and die very quickly in July and August. Interveinal chlorosis and necrosis of the upper leaves (Plate 129 on page 300) and defoliation may occur. Petioles are generally retained. Wet soils and warm temperatures are conducive to disease development. A slight brownish discolouration occurs in crowns of affected plants. The disease is frequently, but not always, associated with soybean cyst nematode.

Disease Cycle:

- All of these fungi survive long periods in crop residue in the soil.
- Brown stem rot infects early in the growing season but does not appear until a month before harvest. Conditions during pod-fill affect disease development. Development is favoured when conditions during pod-fill are cool and wet followed by hot and dry.
- Stem canker prefers moderately warm, wet weather and occurs from mid-July to maturity.
- Sudden death syndrome begins showing symptoms from flowering to maturity and prefers cool, moist soil conditions. Well-fertilized or vigorously growing fields are most likely to show the sudden death syndrome symptoms.

Management Strategies: Crop rotation with corn and cereals will reduce the incidence of disease. These diseases occur most often on reduced tillage fields. Incorporation or removal of infested residue will reduce the risk of these diseases. A few resistant or tolerant soybean varieties are available.

WHITE MOULD *(Sclerotinia sclerotiorum)*

This disease also affects dry edible beans, canola and sunflowers. See *White Mould*, on page 255. and Plates 161–165, on page 305–306.

ASIAN SOYBEAN RUST *(Phakospora pachyrhizi)*

Incidence: Asian soybean rust is a new and invasive fungal disease of soybeans in North America. The threat to the Canadian soybean producer from this destructive disease increases as the disease continues to spread and over-winter in the southern U.S. The confirmation of soybean rust in Ontario during the 2007 growing season shows that although soybean rust does not overwinter in Ontario, the pathway exists and Ontario soybeans can become infected.

Appearance: The most common symptoms are small tan-to-dark brown or reddish-brown lesions, 2–3 mm (⅛ in.) in diameter. Although most often found on the underside of the leaves, they can also occur on petioles, pods and stems. These lesions are raised (pustules), which is where the spores are produced (Plates 130 and 131 on page 300). The tan lesion types will produce more spores than the reddish-brown lesions. Infected leaves will have a mottled appearance. Infection often begins on the lower leaves and moves up the plant. The leaves eventually turn yellow and fall off. It is the loss of photosynthetic tissue, premature defoliation and death that can severely decrease yields. Soybean rust can easily be confused with septoria brown spot, downy mildew or bacterial blight, which are common in Ontario.

Disease Cycle: Soybean rust is a parasite that requires living soybean plants to survive. This is good news to Ontario soybean producers, since the disease will not overwinter in Ontario. Although soybean rust cannot survive the harsh Ontario winters, spores routinely arrive each growing season from their over-wintering locations in the southern U.S. The viability of these spores depends on many factors. The most critical are crop growth stage and the environmental conditions during the time spores are deposited. Long periods of leaf wetness are needed for spore germination, as well as temperatures between 15°C and 30°C and a high relative humidity.

Management Strategies: Currently there is no effective resistance to soybean rust in commercial soybean varieties grown in North America. Soybean rust management depends on scouting, early detection and the use of foliar fungicides, until resistant varieties become available (Plate 132 on page 300). Monitoring or predicting the risk of soybean rust has been aided by the comprehensive North American soybean rust "sentinel plot network," which is available on the Ontario Soybean Growers website at www.soybean.on.ca.

BACTERIAL BLIGHT *(Pseudomonas syringae pv. glycinea)*

Incidence: Most years, the impact of bacterial disease is minimal. Yield losses and seed quality problems can occur when environmental conditions are cool and wet for a prolonged period of the summer.

Appearance: Red or black lesions with a yellow halo and a shiny centre are produced on the leaves of infected plants (Plate 133 on page 301). Symptoms often disappear under dry, hot conditions. Infected seed often has a water-soaked discolouration, starting at the hilum, that can reduce seed viability and reduce germination.

Disease Cycle: The bacteria survives on seed and crop residue and is spread to the upper leaves primarily through rain splash, wind and plant injury (hail, insects, mechanical, etc). There are different physiological races in the province.

Management Strategies:

- crop rotation with crops such as corn and wheat
- removing the crop residue
- staying out of the field while the leaves are wet

There is some tolerance in varieties, but none are resistant to all physiological races.

Pod and Seed Diseases

SOYBEAN MOSAIC VIRUS

Incidence: Low levels of soybean mosaic virus (SMV) occur in most areas of the province. Food grade or specialty beans requiring blemish-free seed coats are at the highest risk of economic losses due to the soybean mosaic virus.

Appearance: Leaves of infected plants are distorted, wrinkled and puckered. They have a typical mosaic pattern that is most evident on younger leaves (Plate 134 on page 301). Infected plants may be stunted. Infected seeds have a characteristic brown or black discolouration extending in streaks from the hilum region (Plate 134 on page 301). Virus symptoms are often confused with hormonal herbicide injury. Plants infected with soybean mosaic virus are scattered in the field, and the affected area is generally smaller than if the cause was herbicide injury. There is no field pattern to the injury.

Disease Cycle: The virus survives from season to season in infected seed and is transmitted from plant to plant by aphids.

Management Strategies: Planting disease-free seed controls the disease in Ontario.

BEAN POD MOTTLE VIRUS

Incidence: Bean pod mottle virus (BPMV) has recently been identified in Ontario. This virus can affect soybean quality and, therefore, export potential.

Appearance: A common symptom of BPMV infection is uneven crop maturity or "green stem" in which stems and leaves remain green, even though pods have matured. Young leaves in the upper canopy often have a green-to-yellow mottling that may fade and then re-develop later in the growing season. In severe cases, malformed leaves and pods may be produced. Infected leaves show reduced turgidity resulting in curling. A reduction in pod set often occurs in infected plants that have undergone moisture stress during dry periods. Infected seed coats are mottled with brown or black streaks extending from the hilum.

Disease Cycle: Cool weather enhances disease development. Unlike soybean mosaic virus, BPMV does not spread very efficiently in seed. The bean leaf beetle is its primary vector, and the cucumber beetle may be a vector as well. The virus has a wide host range among legumes and will be transferred to bean leaf beetles that feed on infected legume plants. The virus can be spread by mechanical injury, especially under wet conditions.

Management Strategies: Plant disease-free seed or resistant varieties in areas with a history of the disease. Consider controlling bean leaf beetle adults when populations are high early in the season. For bean leaf beetle thresholds, see *Bean Leaf Beetle*, on page 210.

FROG-EYE LEAF SPOT *(Cercospora sojina)*

Incidence: Economic impact is usually minimal and is most frequent in the extreme southwest counties.

Appearance: Lesions are 1–5 mm (⅕ in.) in diameter with a tan centre and a dark red/brown border. Older lesions coalesce, and leaves may appear ragged or with a slight slit in the centre of the lesion (Plate 136 on page 301).

Disease Cycle: The pathogen overwinters in residue. Seed and leaf spotting occurs under hot, humid conditions, particularly on very susceptible varieties during flowering and pod development.

Management Strategies:

- crop rotation with non-hosts, such as corn or wheat
- use of non-infected seed
- use of a resistant variety

Foliar fungicides are not often economical unless disease starts early on a very susceptible variety.

CERCOSPORA LEAF SPOT
PURPLE SEED STAIN *(Cercospora kikuchii)*

Incidence: This disease often appears late in the season and can cause leaf blighting and staining of the seed. Yield losses are often minimal, but a reduction in seed quality can occur due to staining.

Appearance: Leaves often have red to purple lesions, less than 1 cm (4/10 in.) in diameter, which become noticeable in August or early September. These lesions can join and form large infected areas that may extend along the midrib or lateral veins. Lesions can also be found on the petioles, stem and pods. Symptoms are often confused with sun scald or ozone damage. Infected seed has a distinctive purple discolouration (purple seed stain), varying from violet to pale purple to dark purple over part or all of the seed coat (Plate 137 on page 301). This discolourization is often confined to the upper two layers of the seed coat. The embryo is not discoloured or affected. In most cases, a 7%–13% reduction in emergence can occur in the field.

Disease Cycle: The fungus overwinters in seed, but the primary infection source is crop residues.

Management Strategies:

- using clean seed and a fungicide seed treatment

- crop rotation and removal of residue to reduce infection potential
- using a variety with greater tolerance

PHOMOPSIS SEED MOULD *(Phomopsis longicolla)* DIAPORTHE POD AND STEM BLIGHT *(Diaporthe phaseolorum)*

Incidence: Historically, phomopsis seed mould has been Ontario's most important soybean seed disease. It is most problematic when the weather conditions at harvest are warm and wet. Delaying harvest under these conditions will increase the incidence of this disease.

Appearance: Phomopsis seed mould is characterized by fine cracks that usually develop near the hilum of the infected seed (Plate 138 on page 301). A white or grey mould may be visible on the seed surface. The yield, grade, viability and vigour of the seed can be reduced. Yield losses occur because severely infected seeds remain small and light and may be lost during harvest and cleaning operations.

The second phase of the disease is referred to as "pod and stem blight." Although plants are infected early in the season, symptoms do not become apparent until after mid-season. Symptoms on the stems appear as small, black, raised dots or bumps (pycnidia) (Plate 139 on page 302). These bumps are arranged in rows or islands on the stem. On the pods, there are also numerous black dots, but they are not arranged in any particular pattern.

Disease Cycle: The fungus overwinters in seed and crop debris. Spores of the fungus are splashed onto developing plants early in the season. Warm, wet and humid weather during pod fill favours disease development.

Management Strategies: Whenever possible, grow full-season varieties that mature during the cool weather late in the growing season. Varieties that are short-season for an area tend to mature earlier when conditions are warmer and more favourable for seed mould development. Pod and stem blight can be controlled or reduced by integrating one or more of the following:

- planting disease-free seed
- planting later
- crop rotation
- plowing under soybean debris
- a well-timed harvest

Harvest soybeans destined for export or seed first. Seed treatment usually increases germination and emergence of seed. However, distorted seed with visible fungal growth often fails to germinate, even when treated.

Alfalfa Diseases

Seedling Diseases

PYTHIUM SEED ROT PYTHIUM DAMPING-OFF PYTHIUM SEEDLING BLIGHT *(Pythium spp.)*

Incidence: Pythium seed rot, damping-off or seedling blight is predominantly an early-season fungal disease of alfalfa. Infection of alfalfa plants most often occurs from the time of planting to several weeks after emergence.

Appearance: Infected seeds may rot. Severely infected seedlings may wilt, collapse and die. Look for wet or watery lesions on the roots and hypocotyl of infected plants. A girdling, pinching or damping-off of the stem at the soil line may be seen, causing the seedling to fall over and die. Fields are most often affected by the disease in circular or irregular patches.

Disease Cycle: Pythium seed rot, damping-off or seedling blight is closely related to phytophthora root rot. Both produce mobile spores that move through the water film between soil particles to locate and subsequently infect alfalfa roots.

Management Strategies: Drain excess soil moisture and avoid compaction. Plant when soil and weather conditions favour rapid emergence and early growth of seedlings. Increase plant populations to compensate for any plant losses. Seed treatments will provide some protection to vulnerable seedlings.

PHYTOPHTHORA ROOT ROT *(Phytophthora medicaginis)*

Incidence: Phytophthora root rot is an important and common disease of alfalfa. The disease shows up mainly on poorly drained soils or on clay loam soils during extended periods of wet weather.

Appearance: Infection occurs as plants emerge, so new seedlings are most at risk. As the stand gets older, the risk declines somewhat. Infected seedlings are stunted, grow slowly due to a reduced root system and eventually begin to wilt (Plate 140 on page 302). A girdling, pinching or damping-off of the stem at the soil line may be seen, causing the seedling to fall over and die. The field is often affected by the disease in circular or irregular patches. In older seedlings or on established plants, a reddish-brown, water-soaked lesion may develop on the roots. In severe cases, root lesions become black, and the taproot may rot entirely. Since the plant is unable to supply water and nutrients, the plant wilts and dies. Lower leaves are yellow at first and as the disease progresses may turn reddish-brown.

Disease Cycle: Phytophthora root rot is a soil-borne disease that can cause root injury or plant death. The fungus survives as thick-walled spores that produce mobile spores in the spring that migrate and infect the plant roots. Water is important since these mobile spores move in the water film between soil particles. Disease development is favoured when moderate to high temperatures occur (21°C–32°C) during humid or wet conditions. Fields that are compacted or poorly drained are especially prone to the disease. The fungus is able to survive for many years in infected plant tissue.

Management Strategies: For fields with a history of phytophthora root rot, use highly resistant varieties and seed treatments. Consult the current edition of the *Ontario Forage Crop Variety Performance Report*, available from an OMAFRA Resource Centre, for variety ratings for phytophthora root rot. Other management practices that help in managing this disease include:

- maintaining good soil fertility, that will promote lateral root growth
- removing excess moisture through improved tile drainage and ensuring reduced compaction
- avoiding other stresses such as leaf-feeding insects, weeds and untimely cuttings that may stress the plants making them more susceptible to phytophthora root rot. Crop rotation has little effect on this disease.

APHANOMYCES ROOT ROT *(Aphanomyces euteiches)*

Incidence: Aphanomyces root rot (ARR) is a potential economically significant alfalfa disease that is considered a major disease in alfalfa seedlings, particularly in wet, saturated soil conditions. ARR also affects surviving adult alfalfa plants and can dramatically reduce yield and vigour of established stands.

Appearance: Infected seedlings are stunted but remain upright, and have yellow leaflets and cotyledons. Roots and stems are grey and water-soaked in appearance. Severely infected seedlings turn light to dark brown.

Classic symptoms in established stands are stunted, yellow plants. Look for the absence of the fine, fibrous roots. Lateral roots are often rotted and even absent. Affected established stands are typically thin, yellow and weedy, and show reduced rhizobia nodulation. Symptoms appear similar to nitrogen deficiency. Regrowth is slow with poor vigour, and therefore yields are low. Because of the stunted root system, infected alfalfa stands do very poorly during seasons with extended dry weather.

Phytophthora tends to kill seedlings more quickly and extensively than ARR by attacking the tap root. However, aphanomyces is considered more chronic, less likely to cause seedling death but more likely to result in stunted, low-yielding alfalfa crops.

Disease Cycle: The fungus survives in the soil on infected plants or debris. For the initial infection to occur, the soil must be saturated. Disease development is favoured when moderate to high temperatures occur (16°C–30°C) during humid or wet conditions. Fields that are compacted or drain poorly are especially prone to the disease.

Management Strategies: Aphanomyces root rot is best managed by using resistant varieties, similar to what has been done with phytophthora-resistant alfalfa varieties. Race 1 and race 2 isolates of aphanomyces have been identified. Race 2 is more virulent. Many alfalfa varieties are resistant to race 1, but far fewer are resistant to race 2. Consult with seed company representatives or see the *Ontario Forage Crop Variety Performance Trial Report* or the website at www.ontario.ca/crops for current information on available ARR resistant varieties. Fungicide seed treatments are not effective against ARR.

BROWN ROOT ROT *(Phoma sclerotioides)*

Incidence: Brown root rot was confirmed in Ontario during the 2007 growing season. It is most likely widespread in the province. It most often occurs in areas with severe winter conditions. The disease is often associated with winterkilled areas, plants that are slow to produce spring growth (slow emergence from winter dormancy) and yield loss.

Appearance: The tap roots, lateral roots and/or crown have characteristic sunken brown lesions (almost black), and in severe cases the tap root is rotted completely. The fungus does not infect the above-ground parts of the alfalfa plant.

Disease Cycle: The brown root rot pathogen thrives when soil temperatures are 15°C or less. Therefore, the fungus is most active in the fall and spring when environmental conditions are favourable for infection and the plants are dormant. Infection of the roots and/or crowns can have a detrimental impact on over-wintering health and promote other diseases, winterkill, stand decline and yield loss. Since the fungus grows very slowly, damage is not often noticed until the second or third year when plants become stunted or die.

Management: Resistant varieties for Ontario are not available. Management strategies to help reduce losses and increase stand longevity include:

- avoiding fall harvest during the critical harvest period (reduce plant stress going into winter)

- maintaining proper soil fertility and rotating out of alfalfa for at least 3 years

Other Crown and Root Rots

Stresses such as leaf diseases, insects, frequent or untimely harvests, winter conditions and low soil pH, increase the severity of crown and root rots. Stresses during the growing season render the plants more susceptible to winter stress. Good crop management practices, especially a good harvesting schedule, and maintenance of adequate soil fertility and proper pH, help reduce disease severity. Control leafhoppers in alfalfa. Avoid mechanical injury of the crowns as much as possible. Crowns are easily injured by machinery and by livestock tramping, especially when the soil is wet.

ANTHRACNOSE (in alfalfa) *(Colletotrichum trifolii)*
NORTHERN ANTHRACNOSE (in red clover) *(Kabatiella caulivora)*

Incidence: In alfalfa, anthracnose occurs mostly in the extreme southwest portion of the province. Northern anthracnose is more widely distributed in red clover fields. Losses in both alfalfa and red clover due to anthracnose can be as high as 25%.

Appearance: Although symptoms can occur on the stem and leaves, it is the damage to the crown area that is most important. Stem symptoms on resistant varieties are small, black, irregular-shaped lesions. Lesions on susceptible varieties are large, sunken and oval to diamond-shaped. These lesions have a tan to straw-coloured centre, with a dark-brown border. When the fungus reproduces, the centre of those stem lesions produced on susceptible varieties will contain small, black, fruiting bodies. These can be easily seen with the eye or a simple hand lens. In severe cases, the lesions will join together and eventually girdle the entire stem, causing wilting or killing of the stem. Dead stems and leaves (shoots) become white and have a characteristic shepherd's hook appearance. These are scattered through the field. They are often confused with two other diseases (rhizoctonia crown rot or fusarium wilt) or frost injury.

Damage to the crown appears as a blue-black discolouration of the crown tissue. Infected plants are easily broken at the base. If the diseased tissue is light brown, the cause is most likely not anthracnose but either rhizoctonia crown rot or fusarium wilt (Plate 141 on page 302). Crown infection results in fewer stems per plant and eventually plant death.

In red clover, northern anthracnose can be very destructive. In addition to most of the symptoms described for alfalfa, infection can result in cracking of the stem surface.

Disease Cycle: The fungus thrives during moderate, humid weather conditions and survives in diseased stems, leaves or debris. Spores produced in the spring are spread by rain. The rain causes splashing, which moves spores from infected plants to neighbouring plants. The fungus can be spread from field to field, through equipment, soil and water erosion.

Management Strategies: Varieties with moderate-to-high resistance to anthracnose are available. Clean harvest equipment between fields. Crop rotation has been found to have limited success in managing the disease in alfalfa, but has had better success in red clover, which does not have the same degree of resistance.

Leaf Diseases

COMMON LEAF SPOT *(Pseudopeziza medicaginis)*
LEPTOSPHAERULINA (LEPTO) LEAF SPOT *(Leptosphaerulina trifolii* or *L. briosiani)*

Incidence: Although both these leaf spot diseases occur in Ontario, common leaf spot is more destructive. Leaf spot infection can cause premature leaf loss and thereby reduce the quality of forage, yield, health and vigour of the crop.

> Lepto leaf spot can be confused with common leaf spot since leaf symptoms begin as small, black spots (1–2 mm (1/16 in.)) that have a light tan or brown centre. A yellow halo usually surrounds the leaf spots. Unlike common leaf spot, these lesions will join together to form larger lesions (Plate 142 on page 302).

Appearance: Leaf spot diseases are first seen on the lower leaves and then develop or move up the plant. Common leaf spot produces small, circular (1–2 mm (1/16 in.)) leaf spots that are brown to black. These lesions rarely join together to form larger lesions. Lesions on the upper leaf surface often have a raised centre. Within these raised centres, the black fruiting bodies (bumps) are easily seen with a hand lens. To be sure, put some infected leaves into a plastic bag with wet paper towels, to help speed the production of these fruiting bodies. Infected leaves become yellow (chlorotic) and drop prematurely.

Disease Cycle: Cool, wet weather favours leaf spot development, so it is found primarily in the early cuttings (spring and early summer) and regrowth (fall). These fungi survive in infected leaves and on dead leaves found on the soil surface. Spores produced on living and dead leaves are spread through the air, where they infect new growth. Young leaves are the most susceptible to leaf spot diseases.

Management Strategies: Timely harvesting of forages is important to reduce leaf loss and minimize disease in the regrowth. Some varieties tolerant of common leaf spot are available, but no resistance or tolerance to lepto leaf spot has been found. There are few practical control strategies available for leaf spot diseases in forages. Leaf spots can reduce the protein level in legume leaves, so it is important to balance the time of harvest between the optimum stage for highest protein and the level of leaf spot disease.

BACTERIAL WILT *(Clavibacter michiganensis)*

Incidence: Bacterial wilt has historically been one of the most important forage diseases, not only in Ontario but anywhere forages are grown. The development of resistant varieties has made the disease less common.

Appearance: Symptoms become apparent as the stand gets older (3 or more years). Infected plants are stunted and have a yellow-green colour. In severe cases, the plant has spindly stems with small, distorted leaves. Infected plants that are stressed by water, heat or both will wilt or die and are scattered throughout the stand. Infection stresses the plant and increases its susceptibility to winterkill. Cutting the taproot in half (in cross-section) will show a light brown-to-yellow discolouration of the vascular tissue near the outer edge.

Disease Cycle: This disease is caused by a soil bacteria that survives in diseased alfalfa roots and in plant debris for at least 10 years. Infection occurs through wounds to the roots and crown or through cut stems. The bacteria causes the plant to wilt since it grows in the vascular system of the plant, thereby blocking water and nutrient movement in the plant.

Management Strategies: All recommended varieties are resistant to the disease. Since the bacteria can be spread through wounds, cut young, less-susceptible stands first and then move to older stands. Harvest stands when the plants are dry. This will limit or reduce potential spread from infected to non-infected plants. The bacteria can be spread in seed and hay.

VERTICILLIUM WILT *(Verticillium albo-atrum)*

Incidence: Verticillium wilt of alfalfa is a disease that increases with stand age. It mainly occurs after the second year of production. The fungus responsible for this disease can be found in most areas of Southern Ontario. Farms with a history of the disease may find dead plants in younger stands (second-year). Verticillium wilt can reduce yields up to 50% and shorten the life of the stand.

Appearance: Initially, a few stems are affected and eventually, the leaves on infected plants wilt, curl inward and become orange-brown or tan-brown (bleached) (Plate 143 on page 302). In the early stages of disease development, leaves will exhibit a V-shaped yellowing of the leaflet tips. Growth is often considerably stunted, and plants eventually die. Although all the plant leaves may die, the stems remain green. The fungus enters through the root or cut stems and is spread from older infected stands to younger stands by harvest equipment, insects and manure application. The disease causes a brown discolouration of the interior root and stem (vascular) tissue. Cutting the stem in half will usually reveal this browning.

Disease Cycle: The *Verticillium* fungus enters the plant primarily through the roots. The fungus blocks or inhibits the plant's ability to move water, resulting in wilting. The fungus survives (overwinters) in infected plant debris. During cool, moist conditions, numerous spores are produced on diseased tissue.

Management Strategies: The disease is best managed by the use of varieties rated as resistant and highly resistant. For variety ratings for verticillium wilt, consult the current edition of the *Ontario Forage Crop Variety Performance Report*, available at an OMAFRA Resource Centre and online at www.plant.uoguelph.ca/performance_recommendations/ofcc/ofcc.htm. Treating seed with a fungicide will help reduce early infection. The fungus is spread primarily on the cutting bar of forage harvesting equipment. Before harvesting, clean the cutting bar with a 1% solution of bleach followed by a clean water rinse and oil spray. Cut the youngest non-infested fields first, working towards the oldest fields. Early harvest can limit yield and quality losses and slow fungus spread from field to field. Wait 2–3 years between alfalfa crops. Maintain a good weed control program, since some weeds can be alternate hosts. For additional information, see the OMAFRA Factsheet, *Verticillium Wilt of Alfalfa*, Order No. 88-036, or the OMAFRA website at www.ontario.ca/crops.

Cereal Diseases

Seedling Diseases

SEED ROT, SEEDLING BLIGHT, ROOT ROT

Incidence and Management Strategies: See *General Seed Rots and Seedling Blights*, on page 227.

Disease Cycle: Organisms that colonize seed and soil are responsible for early-season seed rots and seedling blights, as well as the smut (bunt) diseases of the grain (Plate 144 on page 302). Apply a fungicide seed treatment to all wheat seed to control soil-borne and seed-borne diseases, such as seed rots and seedling blights, seed-borne septoria, seed-borne fusarium seedling blight, seed-borne dwarf bunt, common bunt and loose smut. The best protection against seedling blights, smut and the bunts can be achieved through the use of a seed treatment that contains a combination of fungicides, since no one fungicide is effective against all these diseases. Good seed coverage is essential to maximize performance of seed treatment. Significant yield losses continue to occur from these diseases in fields where fungicide seed treatments have not been used.

FUSARIUM SEEDLING BLIGHT
FUSARIUM CROWN ROT

(F. culmorum, F. graminearum and F. avenaceum)

Incidence: Fusarium seedling blight can be carried on seed or in crop debris. Poor stand establishment, non-uniform emergence, "gaps" or missing plants are primary symptoms of seed or seedling infection (from planting to several weeks after emergence).

Appearance: Seed rots or seedlings are killed before emergence. Seedlings that do emerge are stunted and yellow, with the crown, roots or lower stem having a brown to red-brown rot. Brown or reddish streaks may occur on the stem. Lesions are variable in shape and size and do not have distinct margins. The disease may occur on older plants as well, causing a reduction in the number or size of tillers that mature prematurely with white and shrivelled heads. Plant vigour is reduced in infected plants.

Disease Cycle: These fungi infect many cereals, grasses and other plants, including corn. They survive in seed, in crop residue and in soil. In winter cereals they grow from these sources into the crown, roots or leaf sheaths in the fall. At this stage, they can cause seed decay and seedling blight. In spring, the lesions continue to expand so that crown rot, stem rot and root rot develop. Moist soil in the fall favours infection of the plant, but dry soil and high levels of nitrogen fertilizer favour the progress of the disease in the spring. The fungi, especially *F. graminearum*, also infect heads and contaminate seed. The disease is likely to be more severe on wheat that follows wheat, barley or corn.

Management Strategies: Delay planting until conditions will result in a rapid and uniform emergence. Avoid planting after corn and maintain a balanced fertility program. Fungicide seed treatments are very effective against seed-borne and soil-borne organisms that cause this disease. Other options include the use of tolerant varieties and planting disease-free seed. Use wheat in at least a 3-year crop rotation since these organisms can survive in wheat residues. Avoid planting wheat after corn.

PYTHIUM (BROWNING) ROOT ROT

***(Pythium* spp.)**

Incidence: Pythium root rot damage on wheat is common in Ontario and is one of the primary seedling diseases of small grains. There are several species of *Pythium* that attack small grains and, although *Pythium* is present in all soil types, losses are greatest in cold and wet clay soils. *Pythium* (like *Phytophthora*) is a "water mould" that thrives under wet, saturated conditions. Therefore, infection is very dependent on soil moisture and the clay content of the soil. The wetter the soil and the higher the clay content, the greater the potential for infection. *Pythium* produces mobile spores that migrate through the water film in the soil.

Appearance: Although infection occurs in the embryo 1 or 2 days after planting, seedlings are rarely killed. Infected plants appear stunted with small, pale-green to yellowish leaves. This is often incorrectly identified as a nutrient deficiency. These symptoms often go unnoticed until spring when non-infected plants begin to grow rapidly. Infected roots are light-brown with few or no root hairs. Infection begins at the root tips and disintegrates root hairs and the fine lateral roots, which are critical for nutrient uptake. Affected plants often occur in patches with a general unhealthy appearance. Severely infected plants may break at the soil line.

Disease Cycle: The fungi survive in the soil and crop residues. They produce spores that swim through moisture films on soil particles and invade the wheat roots. Some species are most damaging in warm soils, while others prefer cold soils. The disease is less severe when phosphate levels are adequate for good root growth.

Management Strategies: Minimize soil compaction and remove excess moisture through increased drainage. Seed treatments containing metalaxyl or metalaxyl-M can reduce infection. Delay planting until conditions will result in a rapid and uniform emergence.

TAKE-ALL *(Gaeumannomyces graminis)*

Incidence: Take-all is a fungal disease that can infect wheat, barley, rye, various grasses, and, to a lesser degree, oat.

Appearance: Take-all usually becomes noticeable at the heading stage when the heads, stems and leaves of badly affected plants become prematurely bleached (Plate 145 on page 303). The bleaching of tillers takes only 2 or 3 days. Affected plants occur in circular patches, one to several metres across, or as individuals or small clusters scattered across the field. Many plants appear moderately to severely stunted and bear few tillers. The bleached heads (whiteheads or deadheads) normally are sterile and usually appear 3–5 weeks before harvest. Whiteheads may also be caused by factors other than take-all. Dark-coloured moulds tend to grow on the whiteheads, especially in damp weather. The conspicuous bleaching is secondary to disease on the roots, crown and lower stem.

The roots of diseased plants are sparse, blackened and brittle. The dark-coloured rot often extends to the crown and basal stem. Removal of the lowest leaf sheath reveals a dark shiny layer of fungal material on the stem that is easily scraped off. Weakened stems lean or lodge in various directions as in eyespot. In many instances, the disease is confined to the roots, and no symptoms appear on the crowns, stems and heads. The wheat take-all fungus produces spores inside tiny black structures (perithecia) on the sheath of the lower leaf and on stubble residues at the soil surface.

Disease Cycle: The main source of the fungus is infested crop residues in the soil. The fungus survives best in the residues when the soil nitrogen content is high. Brown strands of the fungus grow from the residues, through the soil and over the surface of the roots, crowns and stems. The fungus spreads from plant to plant by means of "root bridges." Using a hand lens, it is often possible to see the brown strands on the roots while the roots remain whitish. The roots turn black after the fungus penetrates into them. Invaded crowns and stems develop a brownish, dry rot.

The severity of take-all generally increases as soil pH rises and fertility (especially nitrogen and phosphorus) decreases. Wet soil, especially in spring and early summer, is highly favourable to the disease. Soil compaction aggravates take-all. Cool weather (12°C – 18°C) is more favourable than warm weather. The disease is more severe when wheat is sown early than when sown near the end of September or in October. When wheat is grown continually on the same land, take-all becomes increasingly severe during the first 3–5 years but subsequently declines. Take-all predisposes wheat to moisture stress, especially in June and July.

Management Strategies: Carefully manage soil fertility. Neutral to alkaline and infertile soils are most at risk. Do not apply lime before planting. Soils deficient in potassium and phosphorus cause plants to be more susceptible because of poor root development. Nitrate-nitrogen increases disease severity. Control grasses and avoid early planting. Use a 3-year crop rotation and avoid planting wheat after wheat.

Leaf and Stem Diseases

EYESPOT (STRAWBREAKER)
(Tapesia yallundae)
RHIZOCTONIA SHARP EYESPOT
(Rhizoctonia cerealis)

Incidence: The fungi that cause these diseases can have the ability to cause disease in many crops. These diseases become a problem in fields or regions that predominantly grow cereal crops under cool, moist conditions.

Appearance: Eyespot and sharp eyespot produce lesions on the lower sheaths and stems of most cereals (Plate 146 on page 303). Winter wheat is more susceptible than spring cereals. In the spring, both diseases produce elliptical, eye-shaped lesions on the lower internodes near the soil line. Lesions have a dark-brown border with a tan or straw-coloured centre.

Distinguishing between the two diseases is difficult. Rhizoctonia sharp eyespot lesions are more superficial and their margins are sharply defined. Plants infected with eyespot (strawbreaker) have a white fungal growth in the lower stem cavity. In severe cases, plants infected with these diseases may lodge, bend or break at the soil line from a weakening of the stem at the lesion areas. Other symptoms include reduced yields, whiteheads and death of tillers.

Disease Cycle: The eyespot fungus survives in the residue of infected plants for 3 or more years and is most severe under cool, wet conditions. The sharp eyespot fungus survives in the soil and on infected crop residues. Sharp eyespot is most severe in light, dry, acidic soils during cool springs. Dry conditions in the fall and spring favour development of sharp eyespot.

Management Strategies: Avoid planting cereals 2 years in a row, preferably leaving at least 2 years between cereal crops. Practices that bury stubble in the soil are effective in reducing eyespot severity. Eyespot can be severe when the stubble remains on the surface. Sharp eyespot can be severe when crops are planted early and deep. Fungicide seed treatments may reduce losses.

SNOW MOULD *(Microdochium nivale, Typhula spp.)*

Incidence: Although snow moulds do require specific environmental conditions, they occur most years to some degree. Severity increases in years when an early snow cover in the fall (mid-November) persists until late March or April.

Appearance: Snow mould symptoms appear soon after snow melt. Individual plants, groups of plants or large areas can be affected. The most obvious symptom is dead plants that are slimy, brown and rotted (Plate 147 on page 303). Early-planted wheat is usually affected, since lush "top-growth" promotes infection and aids in disease spread from plant to plant. Plants that have not been killed (i.e., have a healthy crown) may have one or many leaves that are totally or partly necrotic (i.e., have brown tips). Symptoms are most pronounced in areas of the field that had heavy snow cover, such as field borders, headlands and down slopes of hills. Typical winter injury on wheat due to other causes will most often occur in areas that had no snow or were covered in ice. Symptoms are pronounced in fields planted with poor-quality or untreated seed. Warm, dry weather in the spring will stop disease development and promote rapid plant growth. Plants with considerable damage often recover from the disease with little or no impact on yield.

Disease Cycle: The group of fungi that cause snow moulds are temperature tolerant and will grow under heavy snow cover. Snow deeper than 30 cm (12 in.) will insulate the soil, preventing it from freezing while maintaining a soil surface temperature at or just above 0°C. Under these conditions, photosynthesis is significantly reduced, and the developing wheat plant has no choice but to use its stored carbohydrates and proteins to survive. The result is a stressed plant that is more susceptible to diseases, especially snow moulds.

Management Strategies: Although no winter wheat cultivar is resistant to the disease, cultivars do differ in tolerance. Seed treatments are very effective against snow moulds, but good seed coverage is essential. In years when snow mould causes substantial reductions in stands, replant to a spring grain or soybean crop. The disease does not affect spring-planted grain.

LEAF RUST *(Puccinia triticinia)*
STEM RUST *(Puccinia graminis)*
STRIPE RUST *(Puccinia striiformis)*

Incidence: There are various species of rust that cause disease on wheat and barley. The three rust diseases that affect wheat are leaf rust, stem rust and stripe rust (see Table 14–3, *Comparison of Common Rusts That Occur on Small Grains in Ontario*, this page). Of these, leaf rust is the most common. It can be found in varying amounts each year and poses the biggest risk to small grain production. Although stem rust has been declining, it may be a serious problem when small grains are grown near the common barberry bush. A new stem rust threat to world wheat production has been developing in other parts of the world. Stripe rust has been increasing over the past few years but is very dependent on early-season environmental conditions. Most years, yield losses from these three rust diseases are low, since disease development often occurs after the winter wheat crop has begun to mature. The earlier rust infection occurs in the crop, the greater the impact on yield.

Table 14–3. Comparison of Common Rusts That Occur on Small Grains in Ontario

	Leaf Rust	**Stripe Rust**	**Stem Rust**
Plant parts affected	leaf	leaf and head	stem and leaf
Lesion (pustule) colour	orange	yellow	dark red
Lesion shape	single	stripes	single
Temperature range	15°C–27°C	12°C–21°C	18°C–30°C
Occurrence in Ontario	yearly – varying amounts	increasing – past 2 years	trace

Appearance: Leaf rust affects the leaf blades and sheath, whereas stem rust can be found on leaves, sheaths, stem and heads. The disease begins as small, yellow-brown pustules that contain orange to orange brown spores (Plate 148 on page 303). In most cases, infection is found on the upper surfaces of the leaves and leaf sheath. In severe cases, leaves turn yellow and brown. In spring grains, late-planted fields are most likely to show the disease, whereas late-maturing winter wheat may be slightly more at risk.

Stem rust begins as dark reddish-brown spots on both sides of the leaves, stems and heads (Plate 149 on page 303). When developed, spots will rupture through the surface, releasing spores into the air. The surface of the tissue appears ragged and torn.

Disease Cycle: Common barberry is necessary for the stem rust fungus to complete its lifecycle. Leaf rust, on the other hand, rarely overwinters in the province but is blown into Ontario on southerly storm fronts from infected plants in the southern U.S. and Mexican wheat regions. In most years, leaf rust spores arrive late (after flowering), resulting in little economic impact. These diseases are most severe when warm temperatures (20°C–28°C in day, 16°C–22°C at night) and frequent dews occur when the crop is at the flag leaf-to-flowering stages (Zadok's 37–71).

Unlike leaf and stem rust, stripe rust does not require an alternate host to complete its life cycle. In addition to wheat, the host range of stripe rust includes many grasses such as rye, barley and many perennial grasses that can act as a reservoir. Stripe rust does not overwinter in Ontario and of the three rust diseases, stripe rust prefers cooler temperatures. Early spring conditions or a prolonged cool period (10°C and 15°C with increased leaf wetness) are ideal for stripe rust development.

Table 14–4. Comparison of BYDV, SBWMV and WSSMV

Virus	Transmission	Major Symptoms	Additional Hosts
Barley yellow dwarf virus	aphids	general chlorosis, reddening, purpling, stunting	barley, oat, corn, sorghum, millet, grasses
Soil-borne wheat mosaic virus	soil-borne fungus *(Polymyxa graminis)*	yellow-green mosaic, stunting, resetting	rye, barley, grasses, sorghum
Wheat spindle streak mosaic virus	soil-borne fungus *(Polymyxa graminis)*	green-yellow mosaic, streaks, spindles	rye, barley

Management Strategies: Removing the alternate host, common barberry, will reduce stem rust. Use tolerant varieties when possible. Since leaf rust usually appears on the upper two leaves first, it is important when scouting for rust to check the second leaf from the top prior to head emergence, and the flag leaf during head emergence, for signs of disease. Use foliar fungicide treatments when the flag leaf has 5–10 pustules or 1% of the flag leaf area is affected (during head emergence to the end of flowering) and the weather forecast predicts rainy, wet weather. Planting spring grains early allows plants to mature before inoculum levels become heavy. In oat, crown (leaf) rust is dependent on European buckthorn as the alternate host.

BARLEY YELLOW DWARF VIRUS

Incidence: Barley yellow dwarf virus (BYDV) has been called the most widely distributed and most destructive virus disease of cereals. BYDV attacks a wide range of grass hosts, including wheat, oat and barley. Of these, oat is considered the most susceptible.

Appearance: The primary symptoms are stunting and yellowing, reddening or purpling of the leaf tips (Plate 150 on page 303). BYDV is often confused with other virus diseases, such as spindle streak mosaic virus and soil-borne mosaic virus, nutrient deficiency or environmental causes (see Table 14–4, *Comparison of BYDV, SBWMV and WSSMV*, this page). Identifying viral pathogens is very difficult and requires accurate serological tests. It is best to send samples to a diagnostic lab with these capabilities.

Disease Cycle: BYDV is transmitted by aphids only. Several species of aphids have been identified as vectors for BYDV, including the greenbug, the corn leaf aphid, the English grain aphid and the bird cherry-oat aphid. Damage occurs as a result of aphid feeding, since aphids feed directly on plant sap and therefore reduce the nutrients available for plant growth. The contact with the plant sap makes aphids ideal vectors for BYDV. It is usually found in patches 1–2 m (6.5 ft) in diameter but can occur uniformly throughout the field if aphid populations are also uniform throughout the field. Yield losses are very dependent on the crop stage when infected. Generally, losses are greater when infection occurs on young seedlings in the fall (>30%), rather than in the spring.

Management Strategies: Few control options are available. In winter cereals, the best strategy is to avoid early planting. Early planting allows the aphids more time to infect the plants in the fall. Recommended or optimum planting dates for winter wheat take into consideration BYDV and Hessian fly and promote a vigorous plant to maximize winter hardiness. See Figure 4–4, *Optimum Date to Seed Winter Wheat Across Ontario*, on page 93. Planting earlier during mild or late autumns allows the aphids to survive longer than usual. Early seeding is an advantage in spring grains. Chemical sprays to control the aphid vectors are not practical or economical, since scouting or detecting the aphids is very difficult. By the time populations reach detectable levels, virus transmission has most likely already occurred. Preventative sprays would not be economic, as BYDV is unpredictable.

SOIL-BORNE WHEAT MOSAIC VIRUS
WHEAT SPINDLE STREAK MOSAIC VIRUS

Incidence: Soil-borne wheat mosaic virus (SBWMV) and wheat spindle streak mosaic virus (WSSMV) are often easily confused with each other since the disease symptoms, life cycle and field pattern are similar. In certain cases, both viruses may be present in the same field.

Appearance: Typical symptoms of SBWMV on wheat leaves is a mosaic of green islands or blotches on a yellow background. Typical leaf symptoms of wheat spindle streak are yellow-to-light green streaks that are parallel to the leaf veins. The streaks are often tapered, which gives the lesions a spindle shape, hence the name. This is in contrast to soil-borne mosaic virus lesions, which are blotches. WSSMV can also cause stunting and reduced tillering in infected plants.

Disease Cycle: It is not uncommon to find that many plants are infected with both viruses since they share a common vector. The common link is a soil-borne fungus called *Polymyxa graminis*. The fungus produces zoospores (swimming spores) that invade root hairs and epidermal cells of young plants during periods of high soil moisture or in low, wet areas of the field. The virus is carried into the plant by the zoospores. The fungus can remain in the soil for at least 8 years. It is not as important to determine which of the two viruses is present as it is to determine that the symptoms are not due to other causes (fungal, bacterial, etc.). Fields at risk are those that have had several crops of winter wheat in the past 8–10 years. Yield losses range from less than 5% to 40%, but generally losses are low. Symptoms usually appear early in the spring when growth resumes. The optimum temperature for symptom development is 5°C–15°C.

Management Strategies: Since the fungal vector for both viruses can survive for many years in the soil, crop rotation as a management option has had limited success. Fields that have been fertilized with liberal amounts of poultry and livestock manures appear to have a reduced wheat spindle streak mosaic virus build-up.

POWDERY MILDEW *(Blumeria graminis f. sp. tritici)*

Incidence: Powdery mildew is a common plant disease that can cause damage when present in wheat and barley fields. Wheat cultivars will vary in their susceptibility to the disease. The yield impact of powdery mildew infections is hard to predict. The disease robs the plant of nutrients and reduces the photosynthetic ability of the leaf. Yield losses are generally minimal from early infections unless the weather remains cool and humid. Mildew infections that attack the flag leaf and the second leaf are more serious. The health of the top two leaves determines the kernel size, test weight and yield. Losses due to powdery mildew have been stated anywhere from 2%–30% of total yield. Very rarely in Ontario have losses been greater than 10%–15%.

Appearance: The characteristic symptom of the disease is the production of a fluffy-white to grey fungal growth that often begins on the lower leaves (Plate 151 on page 304). Infection can move rapidly up the plant on leaves, sheaths, stems and heads under favourable conditions. Leaves develop elongated yellow streaks or areas that may turn brown and die prematurely. Severely diseased plants may lodge or result in poor grain fill. Older, light-grey areas of fungal growth often have small black spots. The white to light-grey fungal growth is most noticeable in the early morning while the plants are still wet. The infection is superficial, and the fungal growth can be easily removed with a finger or a knife.

Disease Cycle: The fungus survives on crop residues, such as straw or stubble, fall-planted winter wheat seedlings, volunteer cereals and wheat. Spores that are released are primarily spread by the wind. The spores require nearly 100% relative humidity and temperatures between 15°C and 21°C. A dense stand and vigorously growing crop can lead to poor leaf-drying conditions, which are favourable conditions for powdery mildew. The disease is very susceptible to weather conditions that promote drying of the crop environment such as hot, dry, sunny weather. Powdery mildew also thrives in fields where high rates of nitrogen have been used. Nitrogen not only increases tiller formation, causing dense stands, but also increases the susceptibility of the crop. Watch for mildew in fields that have had more than 78 kg N/ha (70 lb N/acre). Powdery mildew growth stops when temperatures are above 25°C.

Management Strategies: In most cases, powdery mildew has little impact on rye or oat since these crops are very resistant to the disease. In areas prone to severe mildew, use resistant (tolerant) winter wheat varieties. Removal of crop residue through tillage in conjunction with a crop rotation that limits wheat or other susceptible cereals from being planted in the field for a minimum of 2 years may lower disease risk. Foliar fungicide applications are necessary when disease levels will result in yield losses. Thresholds for fungicide applications differ depending on the age of the crop. Early-season powdery mildew control is warranted when 5%–10% of the lower leaves are infected, which may limit later infection. Later in the season, powdery mildew symptoms on the flag leaf (1% of leaf) and the second leaf (3%–5% of the leaf) require immediate attention, especially if prolonged wet, humid weather is forecast.

Head and Grain Diseases

SEPTORIA LEAF SPOT *(Septoria tritici)*
STAGONOSPORA LEAF AND GLUME BLOTCH *(Stagonospora nodorum)*

Incidence: Septoria leaf spot and stagnospora (septoria) glume blotch are two diseases that are caused by different species of *Septoria*. Both diseases are of economic importance. They attack most small grains and many grasses, but wheat is the only important commercial host.

Appearance: Septoria leaf spot attacks only leaves, whereas stagonospora glume blotch appears on the leaves and glumes. Initial infections from septoria leaf spot appear as small, light green-to-yellow spots between the veins of the lower leaves (Plate 152 on page 304). These spots elongate to form irregular reddish-brown lesions. Embedded in these lesions are small, dark-brown to black fungal bodies (pycnidia) that can be seen easily with the use of a hand lens.

Stagonospora glume blotch develops after the heads emerge and is favoured in warm, humid conditions. Small, oval, irregular, grey-to-brown spots appear on the leaves and purplish-brown areas on the glumes (Plate 153 on page 304). The affected areas are also speckled with small black pycnidia. The presence of pycnidia is an important diagnostic feature that aids in distinguishing septoria leaf spot and stagonospora glume blotch from other leaf spot diseases.

Disease Cycle: *Septoria* fungi survive on seed, straw, stubble or volunteer wheat and are favoured by wet or humid conditions, and moderate temperatures. Along with powdery mildew, leaf diseases caused by *Septoria* are often the first that occur in the spring since they thrive under cool, humid, wet conditions. Although both fungi are limited by hot weather, *Stagonospora* can tolerate somewhat higher temperatures than *Septoria*. Prolonged wet periods in May and early June result in increased disease incidence. The leaf phases of both diseases characteristically move from infected lower leaves upward (secondary disease cycles). The glume stage of stagonospora glume blotch, on the other hand, does not move vertically within the canopy but quickly across the field, infecting only the heads.

Management Strategies: Rotation with crops other than cereals, plowing down cereal residues and removing volunteer wheat will reduce the survivability of these fungi. Unfortunately, in most years, spore levels are sufficient to cause disease under favourable environmental conditions. Balanced fertility programs are important since high rates of fertilizer and early planting may result in dense foliage going into the winter, thus increasing disease levels. Septoria leaf spot may develop under snow cover in winter wheat. Use good-quality seed that has been treated with a fungicide seed treatment to prevent seed-borne infection. Current varieties have limited tolerance. Foliar fungicides provide effective control of septoria leaf spot and stagonospora glume blotch. Application thresholds vary, depending on wheat-growth stage. Applications are justified when one to two lesions (1% of the leaf area) are found on the leaf below the flag leaf up to the boot stage, or when one to two lesions (1% of the leaf area) are found on the flag leaf at head emergence (flowering).

TAN SPOT *(Pyrenophora tritici-repentis)*

Incidence: Tan spot has been increasing in the province as a result of reduced tillage. Economic losses from tan spot have not been significant. However, the disease is often confused with septoria leaf spot, and misdiagnosis could result in unnecessary applications of foliar fungicides. Barley and oat are much more tolerant to tan spot than wheat.

Appearance: Tan spot begins on the lower leaves as small, tan-brown flecks that enlarge into oval- or lens-shaped tan lesions, 5–15 mm (⅕–⅗ in.), with a small, dark brown centre. A bright yellow zone or halo surrounds the tan lesion. The lesion is best viewed when the leaf is held to the sun.

Disease Cycle: The fungus survives on wheat residues. Disease development is favoured when prolonged, cool, cloudy, humid weather occurs early in the growing season. Spores are spread by the wind.

Management Strategies: Most wheat varieties are susceptible to tan spot. Include non-host crops such as other cereals, corn, soybeans and alfalfa in the rotation.

LOOSE SMUT *(Ustilago tritici)*

Incidence: Loose smut has traditionally been one of the most destructive diseases of wheat and barley in Ontario. The use of fungicidal seed treatments manages the disease very effectively. Planting untreated, infected wheat seed can result in yield losses of 10%–30%.

Appearance: Kernels are replaced by dry, black masses of spores, visible soon after heads emerge (Plate 154 on page 304). Over time, all that remains is the naked spike. Infected plants appear normal until heading time.

Disease Cycle: The fungus that causes the disease survives in infected wheat seed and subsequently infects the developing plant. The fungus grows throughout the plant, eventually infecting the head and replacing the grain. Spores are spread by wind and infect adjacent plants. Infected seed appears normal and cannot be separated out. Wheat and barley are the main hosts, whereas oat and rye are quite tolerant.

Management Strategies: Plant pedigree seed that has been treated with seed protectant that contains a systemic fungicide.

FUSARIUM HEAD BLIGHT (SCAB)
(Fusarium graminearum)

Incidence: Fusarium head blight (FHB), or scab, is one of the most important diseases of small grains in Ontario. In recent years, severe outbreaks have occurred when the weather is warm and wet at the flowering to soft-dough stages. Besides the potential for significant yield losses, mycotoxins that are harmful to livestock can be produced.

Appearance: Symptoms of scab become noticeable soon after flowering. Diseased spikelets (glumes and florets) appear to have ripened prematurely (bleached) in contrast to healthy, green heads. The fungus may attack all or only part of the head. Bleaching of the heads or head blight appears 3–5 days after infection. The entire head may be killed when the neck (the stem immediately below the head) is infected (Plate 155 on page 304). During warm, humid weather, the fungus produces a salmon-orange to pink ring of spores at the base of the spikelet or in the crease of the kernel. If conditions continue, the infection may spread to adjacent kernels. Infected kernels are usually shrunken, wrinkled and light in weight. These kernels have a rough, scabby appearance and range in colour from light-brown to pink to greyish-white. The amount of scab on the seed depends on the time of infection and the weather conditions at the time of infection.

The planting of infected seed can result in the development of the seedling blight phase of the disease, which is separate from scab. Infected kernels may not germinate and can result in poor stands. Infected plants that emerge may lack vigour and will often die before they become established. Infected seedlings can appear light to reddish-brown and may be covered with a white or pink mould. As the plants mature, they are usually smaller with few tillers and small heads. If the root or crown is cut, a light-to-reddish-brown root rot can be observed.

Disease Cycle: Although several species of *Fusarium* can cause scab, the principal pathogen is *Fusarium graminearum*, which can infect corn, wheat, barley, oat and rye. All species overwinter in infected kernels, chaff, stubble or straw/stalk residues left on the soil surface. They survive between crops as asexual spores, fungal strands and within dark purplish-black fruiting bodies, which the sexual spores are borne in. The fungi will continue to grow and produce spores from harvest until the crop residues have decomposed in the soil.

Both types of spores can be carried from infected residues of the previous crop by wind or rain splash onto the wheat head. The conidia are produced during warm, moist weather on corn and small grain residues, while the ascospores are released during wet and dry cycles. By doing so, the fungus is able to spread spores into the air for a longer period of time. Spores that land on the head require rainfall or heavy dew to germinate and invade flower parts (anthers, glumes and other portions of the head). The potential for disease increases substantially when these spores land during an extended warm period at 22°C–27°C temperatures with wet, humid weather. The longer it stays wet during flowering, the greater the chance of infection and therefore increased disease severity. If warm, moist weather continues, the salmon-pink spore masses produced on the spikelets will be air-borne and can act as another source of infection.

Management Strategies: Avoid planting wheat following wheat or corn. When residues of either of these crops are left on the surface and wheat is subsequently planted, the chances of FHB infections are greatly increased. Clean plowing of infected residues reduces the risk of infection from spores originating from within the field. However, FHB may still develop from spores blown in from surrounding fields under weather conditions favourable to disease development. As many of the infected kernels are small, shrunken and lighter than sound kernels, it is possible to blow a large proportion of these kernels out the back of the combine by increasing the air blast above normal ranges. This may cause some additional loss of good kernels (up to 0.13 t/ha or 3 bu/acre). Proper storage and drying will limit further FHB development after harvest. The availability of tolerant varieties is increasing and they can reduce infection potential.

Research done at the University of Guelph – Ridgetown Campus on FHB management has led to a mycotoxin prediction model (DONcast). See *Caution* on page 233. The model was developed over many years and is quite innovative since it relates DON accumulation in the wheat grain to the environmental conditions surrounding heading and how it relates to inoculum production, wheat head infection and subsequent fungal growth within the head. See the Weather INnovations Incorporated website at www.weatherinnovations.com/ for more details.

DWARF BUNT *(Tilletia controversa)*
COMMON BUNT *(Tilletia tritici)*

Incidence: Common bunt (stinking or covered smut) occurs anywhere in Ontario where both spring and winter wheat is grown. Dwarf bunt on the other hand, primarily occurs in the counties bordering Georgian Bay and Lake Huron, where snow cover is deep and persistent in late winter and early spring. In severe years, some fields have had over 50% bunt infected plants.

Appearance: In Ontario, there are three fungal species that can cause bunt in winter wheat. The first two are *Tilletia tritici* and *Tilletia laevis*, which cause common bunt or covered smut. The third is *Tilletia controversa*, which causes dwarf bunt in winter wheat. The main symptom of all three of these pathogens is the production of "bunt balls," which replace healthy kernels. These bunt balls contain masses of black powdery fungal spores called teliospores. When infected grain is harvested or crushed, these bunt balls rupture easily, releasing their spore contents, resulting in contamination of the grain. Besides the bunt balls, one of the most obvious signs of these diseases is the pungent, fishy odour of the spores. The odour is important, since the disease has quarantine significance. Many importing countries have zero tolerance for bunt-contaminated wheat shipments. Often the spore cloud and the distinctive odour are the first signs that a crop may have the disease.

Common bunt and dwarf bunt are difficult to distinguish between and often require microscopic examination. One difference is that the bunt balls of common bunt are similar in shape and size to the kernels they have replaced. For dwarf bunt, the bunt balls are smaller and tend to be rounder. Plants infected with dwarf bunt are dramatically shorter (half as tall as healthy plants). Plants infected with common bunt suffer only a slight reduction in height. A fourth bunt fungus causes Karnal bunt or partial bunt. Fortunately, this disease does not occur in Ontario.

Disease Cycle: Dwarf bunt and common bunt can infect winter wheat plants either through the seed (seed-borne) or from the soil (soil-borne). Although common bunt can be soil-borne, the fungus appears to be primarily a seed-borne disease and can be effectively controlled with currently registered seed treatments. Dwarf bunt is harder to control, since spores of the fungus can survive for 10 years or more in the soil.

Management Strategies: Plant seed that is free of bunt spores. Do not keep seed if bunt was present in the field. Some registered seed treatments are more effective than others.

Management Tips:

- **Cut high with the combine.** Wheat infected with dwarf bunt will be substantially shorter than healthy plants. Raising the header will reduce the amount of bunt balls harvested.
- **Harvest below 15% moisture.** Bunt balls and spores that are dry tend to be sent out of the combine easier. The wetter the grain, the more likely bunt spores will adhere to it. Removing wet spore balls through the combine is very difficult since they are very heavy.
- **Set combine wind-blast at maximum.** Turning the wind-blast settings up will remove a large portion of the bunt balls. Minimal good grain will be lost at maximum wind.
- **Harvest fence rows and bush areas separately.** Infection is most severe where snow was the deepest and stayed the longest. Harvesting those areas separately from the rest of the field should minimize the number of bunt balls in the sample.
- **Clean grain before storage.** It is important to remove as many bunt balls as possible from the sample before storage. Bunt balls will rupture during grain handling or removal from the bin. Bunt balls are similar in size to wild buckwheat seed. Therefore, screens that remove wild buckwheat should remove many of the bunt balls in the sample.
- **Put grain into the bin with full aeration.**It will take an extended period of aeration to remove the odour from the sample.

ERGOT *(Claviceps purpurea)*

Incidence: Ergot occurs from time to time on barley, wheat and triticale. Although yield loss in most cases is insignificant, the impact of the disease on grain quality and marketability can be significant, since ergot bodies are toxic to livestock and humans. Exercise caution in feeding grain containing the black ergot bodies to livestock, especially swine. Outbreaks in Ontario are infrequent and sporadic, but ergot can be severe in some fields that have been damaged by frost, herbicide, etc., that resulted in sterile heads. Sterile florets tend to remain open and thus more prone to infection.

Appearance: The first sign of this fungal disease is often the brown to purplish-black sclerotia ("ergot bodies") protruding from the spikelets of the head. These ergot bodies replace the kernels and can be up to 1 cm (½ in.) in length.

Disease Cycle: The fungus survives the winter as sclerotia in the soil and on seed. From here, spores are released that infect the florets and with the aid of insects are transferred to other spikes. Rainy, wet and cool weather that prolongs flowering increases the likelihood of infection. Ergot "sclerotia" are well adapted and can survive for many years in the soil.

Management Strategies: Use clean seed and do not plant seed containing ergots. Allow a minimum of 1 year between other susceptible crops (rye, wheat, barley, triticale).

Barley Diseases

SEEDLING BLIGHT, COMMON ROOT ROT, SPOT BLOTCH *(Cochliobolus sativus)*

Incidence: Spot blotch (Plate 156 on page 304), seedling blight and common root rot are often serious and widespread, and are caused by the same fungus. The fungus overwinters in seed, barley debris and soil. Treat all barley seed with fungicide. To reduce the severity of spot blotch, avoid growing barley after barley, wheat or grasses. Early planting helps avoid serious disease in July. Disease is less severe on barley grown in combination with oat.

NET BLOTCH *(Pyrenophora teres)*
SCALD *(Rhynchosporium secalis)*

Net blotch (Plate 157 on page 305) and scald occur especially in cool, humid seasons. Two-rowed cultivars are usually more susceptible to net blotch and scald than are six-rowed cultivars. To help prevent the build-up of these diseases, avoid growing barley after barley, plow down stubble and straw as completely as possible, and treat seed with fungicide

FUSARIUM HEAD BLIGHT

See *Fusarium Head Blight (Scab)* on page 249.

Oat Diseases

SEPTORIA LEAF BLOTCH
SEPTORIA BLACK STEM

(Phaeosphaeria avenaria)

Septoria leaf blotch in oat can cause severe damage in all recommended varieties. The disease is recognized by the appearance of mottled, light and dark-brown, elongated blotches on the leaf blade, extending to the leaf sheath and culm. Advanced stages on the culm turn black, and the weakened culm breaks over easily, resulting in damage due to lodging. Avoid planting oat after oat or mixed grains.

OAT LEAF RUST
CROWN RUST *(Puccinia coronata var. avenae)*

Crown rust, also called leaf rust, is specific to oat and some wild grasses such as fescue and ryegrass. Oat leaf rust is often serious, and substantial losses can occur, especially in Central and Eastern Ontario.

Appearance: The most distinctive symptoms of the disease is the production of orange pustules (volcanoes) on the oat leaves and sheathes. These pustules can produce thousands of orange-yellow coloured spores that can spread to other fields or infect adjacent plants.

Disease Cycle: The pathogen is not seed- or soil-borne. European buckthorn is the primary local source of spores while another source of spores is blown in from the southern U.S. There are different races of the fungus and they change over time, which can affect a variety's performance over time. Crown rust is most problematic when the disease develops early and the conditions are mild to warm (20°C–25°C) during the day and mild at nights (15°C–20°C) with adequate moisture (rains, frequent dews).

Management Strategies:

- Use a tolerant variety. Varieties differ in their susceptibility to the disease, and, since new rust races develop, this can reduce a variety's tolerance levels. See the *Ontario Performance Trials for Spring Cereal Crops*.
- Plant as early as possible in the spring, which may allow the plants to escape the disease from late-season infection.
- Apply foliar fungicides in a timely manner and close to flag leaf emergence in order to protect the flag leaf.
- Remove or destroy buckthorn.

OAT CYST NEMATODE *(Heterodera avenae)*

Damage by the oat cyst nematode is first noticed about 2 or 3 weeks after oat plants emerge. At that time heavily infected plants appear to suddenly stop growing, leaves turn pale and begin to die back from the tips downward. These plants fail to tiller, resulting in a thin stand of stunted plants that produce little grain. Below ground, the root systems are severely stunted and usually discoloured, from a pale-yellow in early growth to a yellow-brown in mature plants, as compared to the clear-white in healthy plants.

To confirm suspected oat cyst nematode damage, send a sample of several plants with adhering soil to the Pest Diagnostic Clinic. See Appendix I, *Diagnostic Services*, on page 266, for details.

If oat cyst nematodes have caused damage, do not plant spring grains the following year. Use legume or row crops in the rotation. Corn can be used if the nematode population is low but will suffer damage if the soil is heavily infested. The nematode invades corn roots but does not reproduce in them. Therefore, consecutive cropping to corn effectively reduces the population of oat cyst nematodes.

Edible Bean Diseases

General Preventive Measures

- Thoroughly wash all equipment used for cleaning, conveying or planting seed with detergent to remove all soil. Then disinfect the equipment with a quaternary ammonium compound or sodium hypochlorite (for example, 10% Javex). Rinse off the disinfectant with clean water to limit rusting of treated surfaces.
- Use a 3–4-year rotation with non-related crops.
- Do not apply manure containing bean refuse to land intended for beans.
- Stay out of bean fields when the foliage is wet to avoid spreading diseases.

ROOT ROT COMPLEX *(Fusarium solani, Rhizoctonia solani, Pythium spp., Charla basicola)*

Incidence: Numerous organisms cause root rot symptoms on dry edible beans. In Ontario, the four main fungal pathogens are *Fusarium, Pythium, Rhizoctonia* and *Charla*. These organisms can occur individually or in combination, as is often the case. This is referred to as "root rot complex." The amount of damage is related to the general health of the crop, past history, cultivar susceptibility and environmental conditions.

Appearance: Symptoms can appear on plants at any stage of development. Early-season infection results in typical pre-emergence (seed decay) and post-emergence (seedling death) "damping-off" symptoms, thereby reducing plant stands, referred to as poor emergence (Plate 158 on page 305). Plants that survive early infection (damping-off) or become infected later display characteristic "root rot" symptoms, such as discoloured roots, stunting, wilting, etc.

Fusarium root rot begins as small, reddish-brown lesions (in the first few weeks) that, as the plant ages, join to form larger lesions or streaks on the taproot surface. A reddish-brown internal discolouration of the water-conducting tissue can be seen by splitting the taproot, crown and lower stem. Adventitious roots may develop on plants that have a damaged taproot. These adventitious roots are formed above the damaged area. Late infection seldom results in dead plants but rather in stunted, weak-looking ones.

Pythium root rot has a characteristic brown, water-soaked (wet) lesion that starts at the base of the taproot. This lesion advances up the root and stem, eventually stopping 2 or 3 cm (¾–1¼ in.) above the soil line. Seedlings are often killed, resulting in stand establishment problems. Although older seedlings and mature plants may not die from *Pythium* infection, their roots are often pruned, resulting in a stunted, poorly anchored, wilted and unhealthy looking plant.

Rhizoctonia root rot forms reddish-brown, sunken lesions on the stem and taproot, most frequently near the soil line. The lesion can girdle the entire stem, causing stunting or death of the plant. This lesion is distinctively "brick-red" in colour, noticeable immediately after removing the plant from the soil. This is one method of distinguishing rhizoctonia root rot from fusarium root rot. The intensity of the "brick-red" colour will fade rapidly with exposure to the air.

Charla or "black root rot" results in brown to black lesions being formed on the taproot and lateral roots. Under severe conditions, the entire taproot may be black.

Disease Cycle: These fungi survive in the soil in plant debris or as mycelium. They are attracted to the sugars and exudates released by the developing roots. They are most problematic when environmental conditions are cool and wet during planting or when these conditions result in a delay in seedling emergence or development. Mid- to late-season moisture stress (dry conditions) will increase the amount of fusarium and rhizoctonia root rots.

Management Strategies: Eliminating these diseases is not possible, but yield losses from these diseases can be reduced by following good soil management practices:

- Select culitvars that have good general tolerance to root rots.
- Promote root growth through good fertility programs. Keep organic matter content as high as possible.
- Maintain or build up good soil tilth by following a good crop rotation (3 years between bean crops of any kind), not overworking the soil and avoiding working it when it is too wet.
- Remove excessive water through increased tile drainage and minimized compaction.
- Apply seed treatments that will help protect the plant from root rots during germination and early growth.

Bacterial Blights:
COMMON BLIGHT *(Xanthomonas campestris)*
HALO BLIGHT *(Pseudomonas syringae)*

Incidence: There are several bacteria that cause significant damage in dry edible beans. In Ontario, common blight and halo blight are the primary bacterial diseases of this crop. Most bean varieties are susceptible to common bacterial blight, but most are resistant to halo blight.

Appearance: These diseases are difficult to tell apart. Both begin as small, water-soaked spots on the leaflets. In the case of common bacterial blight, these water-soaked lesions are dark and first appear on the underside of the leaflets. These spots enlarge and will join together to form large, brown, dry areas between the veins. Both of these diseases cause a thin, bright yellow border surrounding the infected areas. However, for halo blight, this border is broader and more noticeable (Plate 159 on page 305). Under hot conditions, these borders may not form.

As these blights develop, the infected leaves become brittle and will drop prematurely. Infected plants may lose their leaves a week or two earlier than healthy plants. In severe cases, the small veins and midrib will turn a reddish colour. Leaves infected with halo blight will curl and the younger leaves become yellow, having no noticeable halos or dead spots.

Symptoms on the pods also begin as round, water-soaked lesions with a yellow or cream-coloured mass of bacteria in the centre of these spots. Over time, these pod lesions become sunken and dry with a reddish-brown border surrounding the yellow centre. The earlier the infection occurs on the pods, the greater the impact on seed quality. Seed is often shrivelled and, in the case of common bacterial blight, it may yellow. Planting infected seed produces plants that have a stem girdling or joint rot above the cotyledonary node. The plant is weakened and may fall over.

Disease Cycle: These bacteria do not normally overwinter in Ontario and therefore survive from one year to the next in infected seed. Once the plants are infected, the disease may be spread from infected to healthy plants by storms, people and equipment moving from field to field when the plants are wet. Rain and hail can also spread the bacteria through the field.

Management Strategies: The bacteria usually do not overwinter in the field. However, to be safe, allow one year between susceptible crops. Do not plant seed that has been harvested from infected fields. Also, do not plant this year's crop next to a field that had significant blight in the previous year. Incorporate infected bean debris into the soil after harvest. Bacterial blights spread easily when plants are wet from rain or dew. Stay out of wet fields with equipment and workers. Clean cultivators when moving from field to field. Recently, varieties with genetic resistance to bacterial blight have been developed. These bacterial blight-resistant white bean varieties are becoming available to Ontario growers.

ANTHRACNOSE *(Colletotrichum lindemuthianum)*

Incidence: Anthracnose is a significantly important edible bean disease in Ontario and has been managed with resistant varieties, clean seed and seed treatments. In fields where the disease does develop as a result of new strains of fungus or the use of infected seed, significant damage can occur.

Appearance: Plant symptoms include round, angular or oval lesions on the leaves, stems and pods (Plate 160 on page 305). The lesions are sunken or "crater-like" with a distinct black ring along the edge of the lesion. Often, the centre of the lesion is covered with numerous small, black spore masses. The veins on the lower leaf surface are often red-brown or purple-red. Yield loss is due to early leaf senescence and plant death, shrunken seed and an increase in "pick" (seed that has disease lesions on the seed coat).

Disease Cycle: The fungus survives from year to year primarily as spores or lesions on the seed. Planting clean seed is critical to controlling the disease. Once initial infection occurs in a field, the disease can be spread by the movement of farm machinery, animals and humans, both within the field and between an infected field and a non-infected field. Rainy weather favours this disease, as spores are splashed from diseased areas and carried in wind-borne water droplets or by surface water throughout the field. Wet conditions over a prolonged period of time can result in epidemics.

There are several races (or strains) of anthracnose. All races of the disease cause the same plant symptoms. All of the currently recommended varieties of white bean have good resistance to the beta and gamma races of anthracnose. Consult the OMAFRA Infosheet, *Performance Trials for Dry Edible Beans*, or visit the OMAFRA website at www.ontario.ca/crops each year, for information about varieties resistant to the alpha, delta and potential new races as they develop.

Management Strategies: To avoid anthracnose, plant disease-free seed and use a fungicide seed treatment. Incorporate infected bean debris into the soil after harvest and rotate beans with other non-host crops for at least 2 years. Stay out of bean fields when the plants are wet. To have a seed lot tested for anthracnose, contact your local OMAFRA Resource Centre.

SOYBEAN CYST NEMATODE *(Heterodera glycines)*

Although soybeans are the major host, soybean cyst nematode (SCN) has a wide host range that includes dry edible beans. SCN has been increasing in edible bean-producing areas of the province. Planting dry edible beans into SCN-infested fields can result in an increase in "root rot complex" infection since the nematode damages the roots, allowing for easier access by these organisms. For more information on SCN, see *Soybean Cyst Nematode, on page 235.*

BEAN COMMON MOSAIC VIRUS

Incidence: Bean common mosaic virus has been found wherever dry edible beans are grown in the province. In some years, the disease can be severe in individual fields.

Appearance: Infection of dry edible beans with the virus can cause various symptoms. Leaves of infected plants have a mosaic of light yellow-green and dark-green patches that are puckered. The leaves curl downward along the margin. Plants are stunted and if infection occurs early, they may flower but not produce seed. Another symptom, referred to as "black root reaction," is displayed in varieties containing a specific gene (dominant resistant gene I). These varieties are resistant to all strains of bean common mosaic virus, except when plants growing at high temperatures react to the virus (hypersensitive response), causing the "black root reaction." The result is a browning or blackening of the vascular tissue inside the stem, wilting and plant death. The obvious symptom of "black root reaction" is the discolouration or streaking of the outer stem (water-conducting tissue), which produces a black or brown outer streaking of the stem from the soil line up. This blackening may only be visible on one side of the stem.

Disease Cycle: The virus is primarily spread from field to field through infected seed. Aphids can then spread the virus within the field. Severe losses occur when susceptible varieties are infected early either through infected seed or from being close to other infected plants or fields that have high aphid populations. There are several strains of the virus, but the predominant one in Ontario is strain 1.

Management Strategies: Do not plant seeds harvested from diseased plants. For a list of disease-resistant varieties, consult the OMAFRA Infosheet, *Performance Trials for Dry Edible Beans*, or the OMAFRA website at www.ontario.ca/crops. Avoid damaging the plants during cultivation.

WHITE MOULD *(Sclerotinia sclerotiorum)*

White mould affects dry edible beans, soybeans, canola, buckwheat and sunflowers. See Plates 161–165 on page 305–306.

Incidence in Dry Edible Beans, Soybeans: White mould is a difficult disease to predict, although most years the appearance of the disease is often higher in dry edible beans than in soybeans. The disease is most damaging when cool (moderate), wet conditions occur during flowering or near harvest.

Incidence in Canola, Sunflowers: White mould is a canola disease that is sporadic within a region and varies greatly from year to year. This makes predicting disease potential or outbreaks very difficult. The disease is very destructive during periods of prolonged, wet weather. Losses of up to 50% can occur under ideal conditions.

Appearance in Dry Edible Beans: Initial infection takes place on plant tissue such as older flowers or possibly lower leaves that have died from other causes. Infection of healthy pods, stems and leaves results from infected plant parts coming in contact with healthy plant tissue. Infected areas are bleached, and white tufts of mould (mycelium) are usually present on the plant surface (Plate 161 on page 305). Hard, black sclerotia are produced on the stem surface or within the stem (Plate 162 on page 305).

Appearance in Canola and Sunflower: White mould is characterized by bleached stem lesions and hard black bodies (sclerotia) of white mould fungus inside the stems. It causes premature ripening of the plants (Plate 163–164 on page 306). The disease is often a problem when canola follows canola, white beans, soybeans, buckwheat or sunflowers. Infections that start on the dead blossoms spread to adjacent tissues, resulting in dead branches or dead plants. Plants may lodge. The rotted stems usually have a bleached appearance. Sclerotinia infections can be serious on canola if cool, wet weather occurs in the last 2 weeks of June and continues into early July when blossoming occurs.

White mould can also be a problem in sunflower production. Sclerotinia causes stalk rot (basal stem rot), midstem infections and head rot and leads to large yield reduction (see Plate 165 on page 306).

Management Strategies for Dry Edible Beans:

- Use less-susceptible varieties or varieties with an upright plant stance.
- Do not follow field crops that are susceptible to white mould (such as soybeans, sugarbeets, canola, buckwheat, sunflowers and hemp) with dry edible beans in fields with a history of white mould. If this is not possible, rotate 3 or more years between susceptible crops.
- Increase air movement by planting at recommended rates and proper row widths. This will reduce humidity and make the environment less favourable to white mould development. Avoid excessive use of fertilizers, which results in rapid canopy closure, making the environment favourable to infection by increasing humidity.
- Apply foliar sprays at first bloom, prior to the appearance of disease. Sprays applied after the disease first appears do not control white mould effectively.

Management Strategies for Soybeans: In fields with a history of white mould, avoid growing other host crops, such as canola, dry edible beans, buckwheat and sunflowers, for 3–4 years. Most sclerotia found in the top 2.5 cm (1 in.) of the soil will germinate the year after soybeans. Following soybeans, cropping the field no-till will leave most of the sclerotia on the soil surface, greatly reducing the source of inoculum for future years. Deeply buried sclerotia on the other hand are unlikely to cause a problem for future bean crops when they are brought to the surface through tillage.

Some differences in susceptibility to this disease have been noted between varieties. No resistant varieties have been identified, but field observations indicate that early varieties are less prone to an epidemic than later varieties. Similarly, varieties with greater lodging resistance tend to be more resistant to white mould. For soybean fields with a history of severe white mould infection, consider planting varieties that require 200–300 fewer crop heat units and possess superior resistance to lodging. Foliar fungicides are not recommended since results have been inconsistent.

Do not keep seed from fields infected with white mould.

Management Strategies for Canola: Use clean, certified seed and rotations of at least 4 years, including unaffected crops such as corn, wheat, barley or oat in fields with a history of sclerotinia or white mould. During this rotation, it is necessary to avoid planting susceptible crops, including mustard, sunflower, dry bean, soybean, field pea, lentil or garbanzo bean. At present, no resistant varieties exist. Keep fields clean of broad-leaved weeds since many are alternate hosts for this disease. Foliar fungicide treatments are effective but require scouting and precise timing.

Canola Diseases

SEEDLING DISEASE COMPLEX

Incidence: Stand establishment is a major concern in canola production. Poor stand establishment is often due to seedling disease infection by one or more fungi, which is referred to as a "seedling disease complex." The primary fungi involved are *Rhizoctonia, Fusarium* and *Pythium*. The problem is greatest under cool conditions.

Appearance: Infection can exhibit many symptoms, including seed decay or rot, pre- and post-emergence damping-off, seedling blight and seedling root rot. These symptoms occur during the first 4 weeks or by the fourth-leaf stage. Seeds may fail to germinate or die shortly after emergence. Seedlings that emerge may appear normal but can have significant root rot. Damping-off occurs when root decay or rot moves up the stem (hypocotyl), causing a girdling or pinching of the stem at or near the soil surface. The stem is weakened and is susceptible to breakage or toppling, where the characteristic reddish-brown lesions are formed. Infected seedlings often wilt or die when stressed because of a reduced (root pruning), constricted or rotted root system, especially under dry conditions. Stands are slow to emerge, thin or patchy. Yields can be reduced when stands are uneven or patchy. Severe plant loss may result in reseeding.

Disease Cycle: These fungi survive in the soil on decaying plant residues. Conditions that cause the developing seed or seedling to grow slowly are ideal for these fungi. The below-ground parts of the seedling harden (become woody) at the two- to four-leaf stage and vigorously growing plants reach this stage quicker. At this stage, the seedlings are able to limit further infection and can regenerate roots quicker than they are lost. *Pythium* prefers cool, wet soils, whereas *Rhizoctonia* favours dry, light soils.

Management Strategies: Plant good-quality seed into a firm, moist seedbed when the conditions are suited to promote rapid germination. Fungicide seed treatments will reduce infection and increase stand establishment. Maintain good fertility balance and avoid excess fertilizer, which promotes disease and phytotoxicities. Avoid deep planting of seed.

BLACKLEG *(Leptosphaeria maculans)*

Incidence: Blackleg is a fungal disease that occurs in all canola-growing regions of Canada. In Western Canada, two strains (mild and virulent (severe)) of the fungus are found, causing substantial losses in Western Canada. In recent years, blackleg has been increasing in Ontario, especially in winter canola fields. Fortunately, the severe or virulent strain responsible for losses in the West has not been identified, to date, in Ontario.

Appearance: The first symptoms appear on the cotyledons or leaves as round-to-irregular (1–2 cm (¾ in.)) white to buff lesions that contain numerous small black dots (pycnidia) (Plate 166 on page 306). As the season progresses, the fungus may spread to the stem and crown of the plant, producing a canker that can girdle the stem (Plate 167 on page 306). Severely infected plants ripen prematurely and have a black to grey discolouration at the base of the stem or crown. In severe cases, infected plants will lodge. Seeds of severely infected plants are small and shrivelled and may be infected with the fungus.

Disease Cycle: The blackleg fungus survives on canola residues (refuse) and on infected plants and seed. The fungus can be spread from field to field on canola refuse or diseased plants. The spores of the fungus are also spread by rain, wind and infected seed.

Management Strategies: Use less susceptible varieties. Most varieties are rated on a 1 to 5 (resistant to highly susceptible) scale. Maintain a good crop rotation that has at least 3 years between canola crops. Fungicide seed treatments will reduce seed-borne infection and minimize the risk of introducing blackleg into new fields. However, the disease can still be spread from field to field on infected plants and refuse.

WHITE MOULD *(Sclerotinia sclerotiorum)*

This disease also affects dry edible beans, soybeans and sunflowers. See *White Mould*, on page 255. and Plates 161–165 on page 305–306.

TURNIP MOSAIC VIRUS

Incidence: Turnip mosaic virus (TuMV) has become a significant problem in some areas where winter canola is grown.

Disease Cycle and Appearance: Infection takes place in the fall and causes leaf mottling (yellow or light green areas surrounded by normal green colour) and wrinkling or puckering of the leaf tissue between the veins (Plate 168 on page 306). Spring growth is slow. Severely infected plants are stunted, twisted and generally light-green or yellow. Pods are distorted and a significant proportion of the seeds are poorly filled. The disease appears to be more severe in areas where other cruciferous crops (such as rutabagas) are grown and in fields where pressure from weeds and volunteer cereals is high.

Management Strategies: Volunteer crops of winter canola often have high levels of TuMV infections. Early planting may be helpful in increasing the winter survival of the crop in some areas but appears to also increase the severity of TuMV where the disease is present. Only minor levels of TuMV infection have been observed in spring canola.

Appendices

15. Appendices

Appendix A.

Insect-Monitoring Equipment Supply Companies

BioQuip Products 2321 E Gladwick St. Rancho Dominguez, CA U.S. 90220 Tel: 310-667-8800 Fax: 310-667-8808 Website: www.bioquip.com	Distributions Solida Inc. Tel: 418-826-0900 Fax: 418-826-0901 Website: www.solida.ca/	Gempler's Inc. 1125 Deming Way P.O. Box 449132 Madison, WI 53744 Tel: 1-800-382-8473 Fax: 1-800-551-1128 Website: www.gemplers.com/
Great Lakes IPM 10220 Church Road, NE Vestaburg, MI U.S. 48891 Tel: 989-268-5693 Fax: 989-268-5911 Website: www.greatlakesipm.com/	Quebec Insectes (Atelier Jean Paquet) 3, rue du Coteau P.O. Box 953 Pont-Rouge, Quebec Canada G3H 2E1 Tel/fax: 418-873-2984 Website: www.quebecinsectes.com	

Note: Inclusion in this list does not imply any endorsement or recommendation by the Ontario Ministry of Agriculture, Food and Rural Affairs..

Appendix B.

Corn Nitrogen Rate Worksheet (Imperial) With Detailed Explanation

NITROGEN WORKSHEET: GENERAL RECOMMENDED NITROGEN RATES FOR CORN (IMPERIAL)

The figures in this worksheet are based on a review of N response trials from 1961–2004. The metric version of this worksheet can be found on page 21. The fertilizer rates calculated here are designed to produce the highest economic yield when accompanied by good or above-average management. Research shows that higher rates will occasionally produce higher yields, but usually not enough to pay for the additional fertilizer.

A. Base N Requirement (choose from Table A)	______
B. Yield Adjustment (Yield (bu/acre) ______ x 0.77) =	+ ______
C. Heat Unit Adjustment Your CHU-M1s = ______ Less – 2,800 Total = ______ x 0.037 =	+ ______
D. Previous Crop Adjustment (Choose from Table D)	– ______
E. Price Ratio (PR) Adjustment for Nitrogen Relative to Corn Price (Choose from Table E)	– ______
F. Total N recommendation (A+B+C–D–E)	= ______
G. Deduct Starter N	– ______
H. Deduct Manure N Credits[1]	– ______
I. Preplant Additional N (F–G–H)	= ______
OR	
J. Sidedress Additional N (If Additional N is applied side-dress, multiply value I by the appropriate value in Table J)	______

[1] Manure N Credits can be found in Chapter 9, *Soil Fertility and Nutrient Use*.

Table A. Base N Requirement

	Base N Requirement	
Soil Texture	**Southwestern and Central Ontario**	**Eastern Ontario***
Clay, heavy clay	47	1
Clay loam	36	1
Loam	28	1
Loamy sand	41	17
Sandy loam	34	17
Sand	46	17
Sandy clay, sandy clay loam	38	17
Silt loam	18	1
Silty clay loam	32	1
Silty clay	44	1

* Eastern Ontario includes Frontenac, Renfrew and counties to the east of them.

Table D. Previous Crop Adjustments

Previous Crop	**Adjustment**
Grain Corn	0
Silage Corn	12
Cereals	11
Soybeans	27
Dry edible beans	27
Clover cover crop (plowed)	73
Clover cover crop (no-till)	60
Perennial Forages	
Less than one-third legume	0
One-third-to-half legume	49
Over half legume	98

Table E. Price Ratio (PR) Adjustment for Nitrogen Relative to Corn Price

	Nitrogen Price $/lb N					
Corn Price $/bu	**0.54**	**0.68**	**0.75**	**0.82**	**0.89**	**0.96**
2.60	40	58	67	76	*	*
2.90	33	49	57	65	73	*
3.20	27	41	49	56	64	71
3.50	22	35	42	49	55	62
3.70	19	32	38	45	51	57
4.00	15	27	33	39	45	51
4.30	12	23	29	34	40	45
4.60	9	20	25	30	35	40
4.90	7	17	21	26	31	36
5.20	5	14	18	23	28	32
5.50	3	12	16	20	24	29
5.80	1	9	13	18	22	26

* Adjustments for these price ratios have not been assessed.

Table J. Timing Adjustment (Southwestern and Central Ontario only)

Soil Texture	**Adjustment**
Clay, clay loam, loam, silt loam, silty clay, silty clay loam	0.8
Sandy clay, sandy clay loam, sandy loam	0.9
Sand, loamy sand	1.0

EXPLANATION OF FACTORS IN WORKSHEET

A. Base N Requirement

In most of the province, the medium-textured soils (silt loams and loams) provided the greatest amount of nitrogen to the corn crop, as indicated by the lower "Base N Requirement" (Table A). In both coarser and finer textured soils, the nitrogen requirements are higher.

The data showed a significantly lower requirement for nitrogen in the Ottawa Valley than in the rest of the province, although the reasons for this are not completely clear. This appears to apply in all of the counties east of the Frontenac Axis.

Since these values are derived from the average responses on a wide range of sites, they will represent the expected requirements for soils with "average" characteristics. Any soil that varies from the average (e.g., higher or lower organic matter (OM) content) may differ in the optimum N rates.

B. Yield Adjustment

There is a weak but consistent relationship between fields with higher yields at optimum N rates and higher nitrogen requirements. The yield factor derived from the N response data (0.77 lb N per bushel of yield) is almost exactly equal to the N removal from the field in the grain portion of the crop.

Use average yields for the previous 5 years to estimate the productive capacity of the field. Entering an inflated yield goal into this adjustment will not increase the productivity of the field, will cost money for wasted N and may result in environmental harm. To convert silage yield to an estimate of grain yield, divide the silage yield by 5 for grain yield in tonnes/hectare or tons/acre, or multiply tons per acre by 7 to estimate bushels per acre.

C. Heat Unit Adjustment

Research shows that corn in the long-season areas of the province requires more nitrogen. This may be due to greater moisture stress on the crop in areas with higher average temperatures, which would decrease N use efficiency, or it could be related to differences in soil OM content.

D. Previous Crop Adjustment

The crop that was grown immediately prior to planting corn has a significant impact on the nitrogen requirements. Crops such as grain corn immobilize a significant quantity of mineral N from the soil as the high carbon residue decomposes, and this is reflected in higher N requirements. Forage legume crops fix nitrogen out of the air, which is released to the corn crop as the residue breaks down, resulting in reduced N requirements.

E. Price Ratio Adjustment

The optimum N rate is the point where the yield increase from the last pound of added nitrogen just pays for the extra N. As the cost of nitrogen fertilizer goes up or the value of the corn crop goes down, the amount of yield required to pay for a pound of nitrogen increases. This means that the nitrogen rate that provides the maximum return to added fertilizer is reduced. The amount of reduction in N rates for various combinations of corn and nitrogen price is found in Table E.

For prices outside of the ranges provided, calculate the adjustment to fertilizer rates by following these steps:

- Determine the price of a kilogram of nitrogen. Divide the price per tonne of fertilizer by the number of kilograms of nitrogen in each tonne (the %N multiplied by 10). Calculate the price per pound by multiplying the price per kilogram by 0.45. For example, urea (46% N) at $865 per tonne will have an N price per kilogram of $865/460 kg = $1.88/kg N, or $0.85/lb N.
- Estimate the value of a kilogram (or pound) of corn for the year following harvest (unless the corn has been pre-sold at a fixed price), including all stabilization payments, minus costs for drying, trucking and elevation. Price the value of corn to be fed on-farm at the replacement cost for the corn if it had to be purchased from off farm. The price for a kilogram of corn is the expected price per tonne, divided by 1,000. The price for a pound of corn is the expected net price per bushel divided by 56.
- Calculate the N:corn price ratio, by dividing the price of a kilogram (or pound) of nitrogen into the value of a kilogram (or pound) of corn.
- Subtract 5 from the price ratio, because the N recommendations were developed for a price ratio of 5.
- Multiply the resulting figure by 6.7 (6 for Imperial calculations), and enter this figure into the price ratio adjustment.

F. Total N Recommendation

This figure, calculated by adding values A through E, represents the total N requirements for the crop. This is normally supplied by a combination of starter fertilizer, broadcast or side-dressed fertilizer, and manure.

G. Deduct Starter N

Include any N that is supplied at planting here.

H. Deduct Manure N Credits

Include available nitrogen from manure (or biosolids) on this line. Available N from manure, based on accurate application rates and manure analysis will give more reliable N credits. For estimates of available nitrogen from manure, see Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page 164.

I. Preplant Additional N

The difference between the Total N recommendation, and the credits for starter and manure N, is the amount of nitrogen to be included in a pre-plant application.

OR

J. Sidedress Additional N

Nitrogen that is applied just before the crop needs it is utilized more efficiently than N applied preplant (less opportunity for loss through denitrification or leaching). This difference is most pronounced in the heavier-textured soils. Sandy soils do not normally show a benefit to side-dress N applications. **NOTE:** This adjustment does not apply in Eastern Ontario, where the N recommendations are already relatively low.

Appendix C.

Accredited Soil-Testing Laboratories in Ontario

The following labs are accredited to perform soil tests for pH, buffer pH, P, K, Mg and Nitrate-N on Ontario soils.

Laboratory Name	Address	Telephone/Fax/E-mail	Contact
A & L Canada Laboratories Inc. Website: www.alcanada.com	2136 Jetstream Rd. LONDON, Ont. N5V 3P5	Tel: 519-457-2575 Fax: 519-457-2664 E-mail: aginfo@alcanada.com	Mr. Greg Patterson Mr. Ian McLachlin
Accutest Laboratories A Bodycote Testing Group Company Website: www.bodycotetesting.com	8-146 Colonnade Rd. OTTAWA, Ont. K2E 7Y1	Tel: 613-727-5692, x. 317 Fax: 613-727-5222 E-mail: lorna.wilson@bodycote.com	Mrs. Lorna Wilson
Agri-Food Laboratories Website: www.agtest.com	503 Imperial Rd. Unit #1 GUELPH, Ont. N1H 6T9	Tel: 519-837-1600 1-800-265-7175 Fax: 519-837-1242 E-mail: lab@agtest.com	Mr. Dale Cowan
Brookside Laboratories Inc. Website: www.blinc.com	301 South Main St. NEW KNOXVILLE, Ohio 45871	Tel: 419-753-2448 Fax: 419-753-2949 E-mail: jbrackman@blinc.com	Ms. Jackie Brackman Mr. Mark Flock
FoReST Laboratory Website: http://lucas.lakeheadu.ca/forest/	955 Oliver Rd., BB1005D THUNDER BAY, Ont. P7B 5E1	Tel: 807-343-8026 Fax: 807-343-8116 E-mail: soilslab@lakeheadu.ca	Ms. Claire Riddell Mr. Joel Symonds
University of Guelph Laboratory Services Website: www.labservices.uoguelph.ca/units/soil-nutrient/	University of Guelph P.O. Box 3650 95 Stone Rd. W. GUELPH, Ont. N1H 8J7	Tel: 519-767-6299 Fax: 519-767-6240 E-mail: info@lsd.uoguelph.ca	Mr. Nick Schrier
Stratford Agri-Analysis Website: www.stratfordagri.ca	1131 Erie St. Box 760 STRATFORD, Ont. N5A 6W1	Tel: 519-273-4411 1-800-323-9089 Fax: 519-273-2163 E-mail: info@stratfordagri.ca	Mr. Keith Lemp

There is no official accreditation in Ontario for tissue analysis, but all the accredited soil-testing labs are monitored for proficiency on tissue analyses. For an up-to-date list, visit the OMAFRA website at www.ontario.ca/crops.

Appendix D.
Feed- Mould- and Mycotoxin-Testing Laboratories

A & L Canada Laboratories Inc.
2136 Jetstream Road
London, Ontario
N5V 3P5
Tel: 519-457-2575
Fax: 519-457-2664
www.alcanada.com/

Agri-Food Laboratories
Unit #1
503 Imperial Road North
Guelph, Ontario
N1H 6T9
Tel 519-837-1600 or 1-800-265-7175
Fax 519-837-1242
www.agtest.com/

Intertek Testing Services
960 C Alloy Drive
Thunder Bay, Ontario
P7B 6A4
Tel 807-345-5392

Laboratory Services
University of Guelph
95 Stone Road West
Guelph, Ontario
N1H 8J7
Tel 519-767-6299
www.labservices.uoguelph.ca/labserv/labs-depts.cfm

Shur-Gain
R.R. 4, 600 James Street South
St. Marys, Ontario
N4X 1C7
519-349-2152
http://www.shurgain.com/

Stratford Agri-Analysis
P.O. Box 760
1131 Erie Street
Stratford, Ontario
N5A 6W1
Tel 519-273-4411 or 1-800-323-9089
Fax 519-273-4411
www.stratfordagri.ca

Strathroy Central Laboratory
127 Zimmerman Street South
P.O. Box 303
Strathroy, Ontario
N7G 3W3
Tel 519-245-9600
Fax 519-245-6089

For an updated list, please visit the OMAFRA website at www.ontario.ca/crops

Appendix E.

Soybean Cyst Nematode-Testing Laboratories

A & L Labs Canada East Inc.
2136 Jetstream Road
London, Ontario N5V 3P5
Tel 519-457-2575
Fax 519-457-2664

Agri-Food Laboratories
503 Imperial Road, Unit #1
Guelph, Ontario N1H 6T9
Tel 519-837-1600 or 1-800-265-7175
Fax 519-837-1242

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Road West
Guelph, Ontario N1H 8J7
Tel 519-767-6256
Fax 519-767-6240

Contact these labs for current prices and nematode handling and shipping procedures.

Appendix F.
Ontario Laboratories Offering Custom Seed Germination Testing

Laboratories are accredited by the Canadian Food Inspection Agency.

Canadian Seed Laboratories Ltd. [1,2] P.O. Box 217 208 St. David St. Lindsay, ON K9V 5Z4 Tel 705-328-1648 Fax 705-324-2550	Livingstone Seed Laboratory[1] P.O. Box 27050 Postal Outlet 500 Rexdale Blvd. Etobicoke, ON M9W 6L0 Tel 416-743-7191 Fax 416-743-7191
Hyland Seed Quality Laboratory Box 250 2 Hyland Dr Blenheim, ON N0P 1A0 Tel 519-676-8146 Fax 519-676-5674	Miller Seed Farm R.R. # 2 Bath, ON K0H 1G0 Tel 613-352-7453 Fax 613-352-7453
Kent Agri Laboratory[1] R.R. # 2 Tupperville, ON N0P 2M0 Tel 519-627-3737 Fax 519-627-3737	Perth Seed Laboratory[1] RR #5 Mitchell, ON N0K 1N0 Tel 519-348-9057 Fax 519-348-8165
Lang Germination Lab 6 Clarinda St. P.O. Box 419 Teeswater, ON N0G 2S0 Tel 519-392-8203 Fax 519-392-8203	W.G. Thompson and Sons Ltd. P.O. Box 130 Blenheim, ON N0P 1A0 Tel 519-676-8146 Fax 519-676-5674

[1] Laboratory is also accredited to test for seed purity.

[2] Canadian Seed Laboratories Ltd. is also accredited to do some seed disease testing.

Other labs are accredited by CFIA but only except in-house samples.

Appendix G.

European Corn Borer Economic Threshold Calculations

Use these calculations to estimate if it is economic to treat a non-Bt field with an insecticide. See *European corn borer,* on page 198.

Univoltine Strain (for areas where there is one generation of ECB per year)

A	% shot-holed plants	_____	=	plants with shot-holes ÷ total plants checked
	Unfurl one of the shot-holed plants from each location and look for larvae.			
B	Larvae per plant	_____	=	number of live larvae per unfurled plant x (A)% shot-holed plants ÷ 100
	Example – 25 shot-holed plants and 1.5 larvae per unfurled plant			
	larvae per plant	0.38	=	1.5 x 25 ÷ 100
	A yield loss of 5% per live larvae is estimated.[1] Therefore:			
C	Potential % yield loss	_____	=	(B) x 5 ÷ 100
D	Potential $ loss	_____	=	(C) potential % yield loss x expected yield t/ha (bu/acre) x value $/t ($/bu)
	A 75% effectiveness of a pesticide treatment is estimated.[1] Therefore:			
E	$ preventable loss	_____	=	(D) potential $ loss x % effectiveness of pesticide treatment
F	Treatment cost	_____	=	pesticide cost + application cost
G	Gain (+) or loss (–) if treatment is applied	_____	=	(E) – (F)

[1] Use another estimated value if desired.

Bivoltine Strain (for areas where there are two generations of ECB per year)

A	Larvae per plant	_____	=	number of egg masses/plant x 2 borer / egg mass[1]
	(cumulative counts taken 7 days apart)			
B	% yield loss	_____	=	(A) larvae / plant x 4% yield loss per larvae/plant[2]
C	Yield loss t/ha (bu/acre)	_____	=	% yield loss x expected yield t/ha (bu/acre)
D	$ loss/ha (acre)	_____	=	(C) yield loss t/ha (or bu/acre) x expected $ price per bu
E	Preventable loss per ha (acre)	_____	=	(D) $ loss per ha (or acre) x 75% control[3]
F	Treatment Cost	_____	=	pesticide cost + application cost
G	Gain (+) or loss (–) if treatment is applied	_____	=	(E) – (F)

[1] Assumes a survival rate of 2 larvae per egg mass. This may vary with weather and egg mass size.

[2] Use a 3% loss per borer per plant if infestation occurs after silks are brown. The economic benefit of treatment declines rapidly if infestations occur after the blister stage.

[3] 75% is an average. Use another estimated value if desired.

Appendix H.

Other Contacts

UNIVERSITY OF GUELPH

Main Campus
Guelph, N1G 2W1
519-824-4120
www.uoguelph.ca

Alfred College
Alfred, K0B 1A0
613-679-2218
www.alfredc.uoguelph.ca/

Kemptville College
Kemptville, K0G 1J0
613-258-8336
www.kemptvillec.uoguelph.ca

Ridgetown College
Ridgetown, N0P 2C0
519-674-1500
www.ridgetownc.on.ca

DEPARTMENT OF PLANT AGRICULTURE

www.plant.uoguelph.ca

Department of Plant Agriculture, Kettleby
1125 Woodchopper's Lane
R.R. # 1, Kettleby, L0G 1J0
905-775-3783

Department of Plant Agriculture, Simcoe
1283 Blue Line Rd. Box 587
Simcoe, N3Y 4N5
519-426-7127

Department of Plant Agriculture, Vineland
4890 Victoria Ave. N. Box 7000
Vineland Station, L0R 2E0
905-562-4141

LAB SERVICES DIVISION

www.uoguelph.ca/labserv/

Trace Organic and Pesticide Contaminants
95 Stone Road West
Guelph, N1H 8J7
519-823-1268

Pest Diagnostic Clinic
95 Stone Road West
Guelph, N1H 8J7
519-767-6256

AGRICULTURE & AGRI-FOOD CANADA

Research Centres

Eastern Cereals and Oilseeds Research Centre
960 Carling Avenue
Ottawa, K1A 0C6
613-759-1952
http://res2agr.ca/ecorc/index_e.htm

Greenhouse and Processing Crops Research Centre
2585 County Rd 50
Harrow N0R 1G0
519-738-2251
http://res2.agr.ca/harrow/

Southern Crop Protection and Food Research Centre
1391 Sandford St
London N5V 4T3
519-457-1470
http://res2.agr.ca/london.index_e.htm

Vineland Research Farm
4902 Victoria Ave. N
Vineland L0R 2E0
905-562-4113

Delhi Research Farm
711 Schafer Side Rd, Box 186
Delhi N4B 2W9
519-582-1950

CANADIAN FOOD INSPECTION AGENCY

www.cifa-acia.agr.ca

Regional Offices (Plant Protection)

Belleville
345 College Street East
Belleville K8N 5S7
613-969-3333

Hamilton
709 Main St.W. 101
Hamilton, L8S 1A2
905-572-2201

London
1200 Commisioners Road East, Unit 19
London, N6A 3E3
519-691-1306

Niagara Falls
350 Ontario St. Unit 13
Box 9
St Catherines N2R 5L8
905-937-7343

Brantford
Federal Building, Dalhousie & Queen St
PO Box 637
Brantford N3T 5P9
519-753-3487

Ottawa District
3 Observatory Crescent, Bldg., #3 Central Experimental Farm, Ottawa
K1A 0C9
613-759-1571

Toronto Office
1124 Finch Ave W, Unit 2
Downsview, M3J 2C6
416-665-5055

Windsor
2000 Continental Ave
Windsor N9E 3P1
519-969-2522

Appendix I.

Diagnostic Services

Samples for disease diagnosis, insect or weed identification, nematode counts and verticillium testing can be sent to:

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Rd. W.
Guelph, ON N1H 8J7

Tel: 519-767-6256
Fax: 519-767-6240
E-mail: pdc@lsd.uoguelph.ca

Payment must accompany samples at the time of submission. Submission forms are available at http://www.labservices.uoguelph.ca/units/pdc/.

FEE SCHEDULE

To obtain information on the fee schedule, refer to http://www.labservices.uoguelph.ca/units/pdc/or phone the Pest Diagnostic Clinic.

HOW TO SAMPLE FOR NEMATODES

Soil

When to sample

Soil and root samples can be taken at any time of the year that the soil is not frozen. In Ontario, nematode soil population levels are generally at their highest in May and June and again in September and October.

How to sample soil

Use a soil sampling tube, trowel or narrow-bladed shovel to take samples. Sample soil to a depth of 20–25 cm (8–10 in.). If the soil is bare, remove the top 2 cm (1 in.) prior to sampling. A sample should consist of 10 or more subsamples combined. Mix well. Then take a sample of 0.5–1 L (1 pint–1 quart) from this. No one sample should represent more than 2.5 ha (6.25 acre). Mix subsamples in a clean pail or plastic bag.

Sampling pattern

If living crop plants are present in the sample area, take samples within the row and from the area of the feeder root zone (with trees, this is the drip line).

Number of subsamples

Based on the total area sampled:

500 m^2 (5,400 ft^2)	10 subsamples
500 m^2–0.5 ha (5,400 ft^2–1.25 acre)	25 subsamples
0.5 ha–2.5 ha (1.25–6.25 acre)	50 subsamples

Roots

From small plants, sample the entire root system plus adhering soil. For large plants, 10–20 g (½–1 oz.), dig fresh weight from the feeder root zone and submit.

Problem areas

Take soil and root samples from the margins of the problem area where the plants are still living. If possible, also take samples from healthy areas in the same field. If possible, take both soil and root samples from problem and healthy areas in the same field.

SAMPLE HANDLING

Soil samples

Place in plastic bags as soon as possible after collecting.

Root samples

Place in plastic bags and cover with moist soil from the sample area.

Storage

Store samples at 5°C–10°C (40°C–50°F) and do not expose them to direct sunlight or extreme heat or cold (freezing). Only living nematodes can be counted. Accurate counts depend on proper handling of samples.

SUBMITTING PLANT FOR DISEASE DIAGNOSIS OR IDENTIFICATION

Sample submission forms

Forms can be obtained from your local Ontario Ministry of Agriculture, Food and Rural Affairs office. Carefully fill in all of the categories on the form. In the space provided, draw the most obvious symptom and the pattern of the disease in the field. It is important to include the cropping history of the area for the past three years and this year's pesticide use records.

Choose a complete, representative sample showing early symptoms. Submit as much of the plant as is practical, including the root system or several plants showing a range of symptoms. If symptoms are general, collect the sample from an area where they are of intermediate severity. Completely dead material is usually inadequate for diagnosis.

With plant specimens submitted for identification, include at least a 20–25-cm sample of the top portion of the stem with lateral buds, leaves, flowers or fruits in identifiable condition. Wrap plants in newspaper and put in a plastic bag. Tie the root system off in a separate plastic bag to avoid drying out and contamination of the leaves by soil. Do not add moisture, as this encourages decay in transit. Cushion specimens and pack in a sturdy box to avoid damage during shipping. Avoid leaving specimens to bake or freeze in a vehicle or in a location where they could deteriorate.

Delivery

Deliver to the Pest Diagnostic Clinic as soon as possible by first class mail or by courier at the beginning of the week.

SUBMITTING INSECT SPECIMENS FOR IDENTIFICATION

Collecting samples

Place dead, hard-bodied insects in vials or boxes and cushion with tissues or cotton. Place soft-bodied insects and caterpillars in vials containing alcohol. Do not use water, as this results in rot. Do not tape insects to paper or send them loose in an envelope.

Place live insects in a container with enough plant "food" to support them during transit. Be sure to write "live" on the outside of the container.

UNIVERSITY of GUELPH LABORATORY SERVICES

95 Stone Road West
Guelph, ON N1H 8J7
Tel: (519) 767-6256
Fax: (519) 767-6240
Web: www.uoguelph.ca/pdc

Pest Diagnostic Clinic

SAMPLE SUBMISSION FORM

LABORATORY USE ONLY: **LS Form: SubP01/04/03** **Pg. 1 of 1**
Rec'd: By:__________ **Date Received:** __________
Delivered By: ☐ **Mail** ☐ **Courier** ☐ **In-Person**
LS Sample No: __________ **to** __________
Payment Rec'd: $__________ **Receipt #:**__________

Submitted By:			Owner (if different from submitter):		
Business Name (if applicable):			Business Name (if applicable):		
Street:			Street:		
City:	Prov:	Postal Code:	City:	Prov:	Postal Code:
Tel: ( ) -	Fax: ( ) -		Tel: ( ) -	Fax: ( ) -	
Email:			Email:		

Unless otherwise indicated, report and invoice will be sent to submitter
Report to: ☐ Submitter ☐ Owner Required Report Format: ☐ Fax ☐ E-Mail ☐ Mail
Invoice to: ☐ Submitter ☐ Owner Quotation #: ________ Purchase Order / U of G G/L code:__________

Services Required: ☐ Nematode Count ☐ Nematode Count from Roots ☐ SCN Cyst & Egg Count
☐ Plant Disease Diagnosis ☐ Insect Identification ☐ Plant Identification ☐ Verticillium Count

Plant or Host Affected:		Cultivar/Variety:	Grower/Field sample #:
		Location of Plant (i.e. greenhouse, field, orchard, garden, etc.):	
Size of Planting:	% of Plants Affected:	Symptoms First Appeared in Past: ☐ Days ☐ Weeks ☐ Months ☐ Years	Degree of Injury: ☐ Severe ☐ Moderate ☐ Light
Cropping History:		Future Crop:	

Describe the problem in detail (i.e. symptoms, plant parts affected, distribution of symptoms):

Were chemicals applied? Please specify type of product(s) used and date(s) of application:

Additional comments and specific requests:

Additional Sheet(s) Attached: ☐

Appendix J.

Plant Populations at Various Row Widths

Row Width		Length of Row Equal to 1/1,000 acre[1,2]	
centimetres	inches	metres	feet
38	15	10.6	34 ft. 10 in.
51	20	8.0	26 ft. 1 in.
56	22	7.3	23 ft. 10 in.
71	28	5.7	18 ft. 8 in.
76	30	5.3	17 ft. 5 in.
81	32	5.0	16 ft. 4 in.
86	34	4.7	15 ft. 5 in.
91	36	4.4	14 ft. 6 in.
97	38	4.2	13 ft. 9 in.

[1] To obtain the number of plants per one-thousandth hectare, multiply the number of plants in the length of row by 2.47.

[2] Multiply the number of plants counted in the length of row above by 1,000 to determine the number of plants/acre.

Appendix K.

Hula Hoop Method for Determining Plant and Pest Populations

Inside Diameter of Hoop in Centimetres (inches)	Square Area in Metre^2 (ft^2)	Factor by Which to Multiply the Number of Plants Within the Hoop to Equal:	
		Plants per Hectare	Plants per Acre
91 (36)	0.65 (7.0)	15,385	6,165
84 (33)	0.55 (6.0)	18,182	7,334
76 (30)	0.45 (4.9)	22,222	8,874
69 (27)	0.37 (4.0)	27,027	10,956
61 (24)	0.29 (3.2)	34,483	13,865
Inside dimensions of a square frame in centimetres (in.)			
50 x 50 (20 x 20)	0.25 (2.7)	40,000	16,133
100 x 100 (40 x40)	1.00 (11.1)	10,000	3,924

Count the number of plants that are found within the hoop or square and multiply that number by the pre-determined factor listed above to determine plant population per hectare or acre.

Appendix L.

Commercial Grain Seeding Rates, Test Weights and Moisture Contents

	Seeding Rate	Seed Weight			Moisture
Crop	**kg/ha**	**kg/hl**	**lb/bu[1]**	**g/0.5L**	**%**
Wheat (winter & spring)	100–130	74.8	60	365	14.0
Oat	60–110	42.4	34	192	13.5
Barley (winter & spring)	80–160	59.9	48	288	14.8
Rye	70–95	69.9	56	339	14.0
Triticale	75–100	65	52	—	—
Corn (field)	11–22	69.9	56	353	15.5
White Beans (70-cm rows)	40–45	75	60	—	—
Soybeans	65–155	74.8	60	382	13.0
Peas (field)	130–200	75	60	—	—
Buckwheat	55	59.8	48	294	45.6
Flax seed	40	69.9	56	331	10.0
Canola (spring & winter)	45	62	50	—	10.5
Millet (proso)	40	70	56	—	—
Sunflower oilseed	4	33.6	27	162	9.5
Sunflower stripes (confectionary)	6	39.9	24	149	9.5
Mustard (yellow)	8–11	70	56	—	—
Sudangrass	14	50	40	—	—
Sorghum	14	70	56	—	—
Annual canarygrass	35	62	50	—	—
Lupins	150–180	75	60	—	—

Source: Canadian Grain Commission

[1] lb/Avery bushel

Appendix M. The Metric System

METRIC UNITS

Linear Measures (length)

10 millimetres (mm)	=	1 centimetre (cm)
100 centimetres (cm)	=	1 metre (m)
1,000 metres (m)	=	1 kilometre (km)

Square Measures (area)

100 m x 100 m = 10,000 m^2	=	1 hectare (ha)
100 hectares	=	1 square kilometre (km^2)

Cubic Measures (volume)

Dry Measure

1,000 cubic millimetres (mm^3)	=	1 cubic centimetre (cm^3)
1,000,000 cubic centimetres (cm^3)	=	1 cubic metre (m^3)

Liquid Measure

1,000 millilitres (mL)	=	1 litre (L)
100 litres (L)	=	1 hectolitre (hL)

Weight-Volume Equivalents (for water)

(1.00 kg) 1,000 grams	=	1 litre (1.00 L)
(0.50 kg) 500 grams	=	500 millilitres (0.50 L)
(0.10 kg) 100 grams	=	100 millilitres (0.10 L)
(0.01 kg) 10 grams	=	10 millilitres (0.01 L)
(0.001 kg) 1 grams	=	1 millilitre (0.001 L)

Weight Measures

1,000 milligrams (mg)	=	1 gram (g)
1,000 grams (g)	=	1 kilogram (kg)
1,000 kilograms (kg)	=	1 tonne (t)
1 milligram/kilogram	=	1 part per million (ppm)

Dry-Liquid Equivalents

1 cubic centimetre (cm^3)	=	1 millilitre (mL)
1 cubic metre (m^3)	=	1,000 litres (L)

APPLICATION RATE CONVERSIONS

Metric to Imperial or US (Approximate)

litres per hectare x 0.09	=	gallons per acre
litres per hectare x 0.11	=	US gallons per acre
litres per hectare x 0.36	=	quarts per acre
litres per hectare x 0.36	=	US quarts per acre
litres per hectare x 0.71	=	pints per acre
litres per hectare x 0.86	=	US pints per acre
millilitres per hectare x 0.015	=	fluid ounces per acre
grams per hectare x 0.015	=	ounces per acre
kilograms per hectare x 0.89	=	pounds per acre
tonnes per hectare x 0.45	=	tons per acre

Imperial or US to Metric (Approximate)

gallons per acre x 11.23	=	litres per hectare (L/ha)
gallons US per acre x 9.35	=	litres per hectare (L/ha)
quarts per acre x 2.8	=	litres per hectare (L/ha)
quarts US per acre x 2.34	=	litres per hectare (L/ha)
pints per acre x 1.4	=	litres per hectare (L/ha)
pints US per acre x 1.17	=	litres per hectare (L/ha)
fluid ounces per acre x 70	=	millilitres per hectare (mL/ha)
fluid ounces US per acre x 73	=	millilitres per hectare (mL/ha)
tons per acre x 2.24	=	tonnes per hectare (t/ha)
pounds per acre x 1.12	=	kilograms per hectare (kg/ha)
pounds per acre x 0.45	=	kilograms per acre (kg/acre)
ounces per acre x 70	=	grams per hectare (g/ha)

Fertilizer Conversions

K_2O	x	0.83	=	K (elemental)
P_2O_5	x	0.44	=	P (elemental)
Phosphorus (P)	x	2.29	=	P_2O_5
Potash (K_2O)	x	0.83	=	Potassium (K)
Potassium (K)	x	1.2	=	Potash (K_2O)

Metric Conversions

5 mL	=	1 tsp
15 mL	=	1 tbsp
28.5 mL	=	1 fl. oz

Appendix M. The Metric System (continued)

DRY WEIGHT EQUIVALENTS

Metric		Imperial
100 grams/hectare (g/ha)	=	1½ ounces/acre (oz/acre)
200 grams/hectare (g/ha)	=	3 ounces/acre (oz/acre)
300 grams/hectare (g/ha)	=	4¼ ounces/acre (oz/acre)
500 grams/hectare (g/ha)	=	7 ounces/acre (oz/acre)
700 grams/hectare (g/ha)	=	10 ounces/acre (oz/acre)
1.10 kilograms/hectare (kg/ha)	=	1 pound/acre (lb/acre)
1.50 kilograms/hectare (kg/ha)	=	1¼ pounds/acre (lb/acre)
2.00 kilograms/hectare (kg/ha)	=	1¾ pounds/acre (lb/acre)
2.50 kilograms/hectare (kg/ha)	=	2¼ pounds/acre (lb/acre)
3.25 kilograms/hectare (kg/ha)	=	3 pounds/acre (lb/acre)
4.00 kilograms/hectare (kg/ha)	=	3½ pounds/acre (lb/acre)
5.00 kilograms/hectare (kg/ha)	=	4½ pounds/acre (lb/acre)
6.00 kilograms/hectare (kg/ha)	=	5¼ pounds/acre (lb/acre)
7.50 kilograms/hectare (kg/ha)	=	6¾ pounds/acre (lb/acre)
9.00 kilograms/hectare (kg/ha)	=	8 pounds/acre (lb/acre)
11.00 kilograms/hectare (kg/ha)	=	10 pounds/acre (lb/acre)
13.00 kilograms/hectare (kg/ha)	=	11½ pounds/acre (lb/acre)
15.00 kilograms/hectare (kg/ha)	=	13½ pounds/acre (lb/acre)

LIQUID EQUIVALENTS

Litres/Hectare		Approximate Gallons/Acre
50	=	5
100	=	10
150	=	15
200	=	20
250	=	25
300	=	30

SPEED

miles per hour	x	88	=	feet per minute
miles per hour	x	1.467	=	feet per second
miles per minute	x	88	=	feet per second
miles per minute	x	60	=	miles per hour
feet per minute	x	0.01667	=	feet per second
feet per minute	x	0.01136	=	miles per hour
feet per second	x	18.288	=	metres per minute
feet per second	x	0.3048	=	metres per second
feet per second	x	1.09728	=	kilometres per hour
centimetres per second	x	1.968504	=	feet per minute
centimetres per second	x	0.0328084	=	feet per second
centimetres per second	x	0.02236936	=	miles per hour
kilometres per hour	x	27.777778	=	centimetres per second
kilometres per hour	x	3280.8399	=	feet per hour
kilometres per hour	x	54.680665	=	feet per minute
kilometres per hour	x	0.6213712	=	miles per hour
miles per hour	x	1.6093439	=	kilometres per hour

ABBREVIATIONS

%	= per cent (by weight)	km/h	= kilometres per hour
ai	= active ingredient	kPa	= kilopascal
AP	= agricultural powder	L	= litre
cm	= centimetre	m	= metre
cm^2	= square centimetre	m/sec	= metres per second
DG	= dispersible granular	m^2	= square metre
DP	= dispersible powder	mL	= millilitre
E	= emulsifiable	mm	= millimetre
e.g.	= for example	SC	= sprayable concentrate
EC	= emulsifiable concentrate	SP	= soluble powder
F	= flowable	t	= tonne
g	= gram	W	= wettable (powder)
Gr	= granules, granular	WDG	= water dispersible granular
ha	= hectare	WP	= wettable powder
kg	= kilogram	km/h	= kilometres per hour

Appendix M. The Metric System (continued)

CONVERSION TABLES — METRIC TO IMPERIAL

Length

1 millimetre (mm)	=	0.04 inch (in.)
1 centimetre (cm)	=	0.40 inch (in.)
1 metre (m)	=	39.40 inches (in.)
1 metre (m)	=	3.28 feet (ft)
1 metre (m)	=	1.09 yards (yd)
1 kilometre (km)	=	0.62 mile (mi)

Area

1 square centimetre (cm^2)	=	0.16 square inch (in^2)
1 square metre (m^2)	=	10.77 square feet (ft^2)
1 square metre (m^2)	=	1.20 square yards (yd^2)
1 square kilometre (km^2)	=	0.39 square mile (mi^2)
1 hectare (ha)	=	107,636 square feet (ft^2)
1 hectare (ha)	=	2.5 acres (acre)

Volume (dry)

1 cubic centimetre (cm^3)	=	0.061 cubic inch (in.^{3})
1 cubic metre (m^3)	=	1.31 cubic yards (yd^3)
1 cubic metre (m^3)	=	35.31 cubic feet (ft^3)
1,000 cubic metres (m^3)	=	0.81 acre-foot
1 hectolitre (hL)	=	2.8 bushels (bu)

Volume (liquid)

1 millilitre (mL)	=	0.035 fluid ounce (Imp)
1 litre (L)	=	1.76 pints (Imp)
1 litre (L)	=	0.88 quart (Imp)
1 litre (L)	=	0.22 Imperial gallons (gal)
1 litre (L)	=	0.26 U.S. gallon (U.S. gal)

Weight

1 gram (g)	=	0.035 ounce (oz.)
1 kilogram (kg)	=	2.21 pounds (lb)
1 tonne (t)	=	1.10 short tons
1 tonne (t)	=	2,205 pounds (lb)

Pressure

1 kilopascal (kPa)	=	0.15 pounds/square inch (lb/in^2)

Speed

1 metre per second (m/sec)	=	3.28 feet per second (ft/sec)
1 metre per second (m/sec)	=	2.24 miles per hour (mph)
1 kilometre per hour (km/h)	=	0.62 mile per hour (mph)

Temperature

°F	=	(°C x $\frac{9}{5}$) + 32

CONVERSION TABLES — IMPERIAL TO METRIC

Length

1 inch (in.)	=	2.54 centimetres (cm)
1 foot (ft)	=	0.30 metre (m)
1 yard (yd)	=	0.91 metre (m)
1 mile (mi)	=	1.61 kilometre (km)

Area

1 square foot (ft^2)	=	0.09 square metres (m^2)
1 square yard (yd^2)	=	0.84 metre (m^2)
1 acre (ac)	=	0.40 hectare (ha)

Volume (dry)

1 cubic yard (yd^3)	=	0.76 cubic metre (m^3)
1 bushel (bu)	=	36.37 litres (L)

Volume (liquid)

1 fluid ounce (Imp.)	=	28.41 millilitres (mL)
1 pint (Imp.)	=	0.57 litre (L)
1 gallon (Imp.)	=	4.55 litres (L)
1 gallon (U.S.)	=	3.79 litres (L)

Weight

1 ounce (oz)	=	28.35 grams (g)
1 pound (lb)	=	453.6 grams (g)
1 ton	=	0.91 tonne (t)

Pressure

1 pound per square inch (lb/in^2)	=	6.90 kilopascals (kPa)

Temperature

°C	=	(°F–32) x $\frac{5}{9}$

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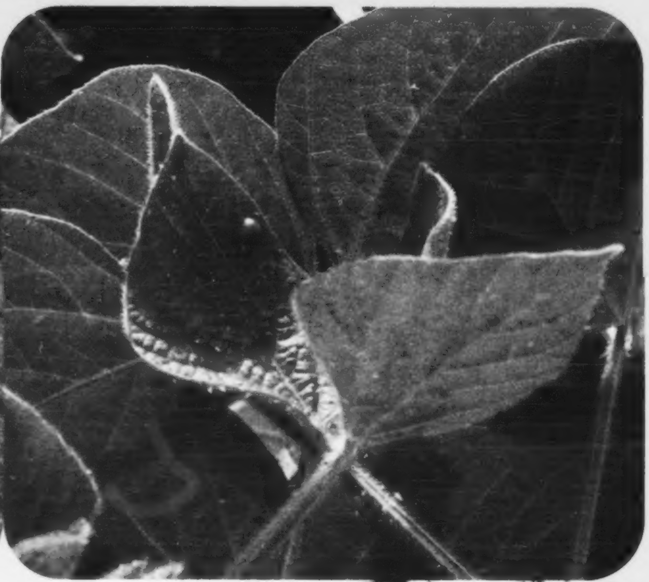


17. Colour Plates

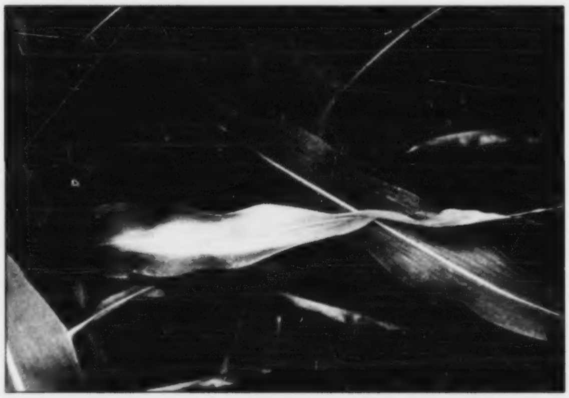


Plate 1. Nitrogen deficiency shows up on lower leaves first. Yellowing begins at the leaf tip and proceeds down the midrib.

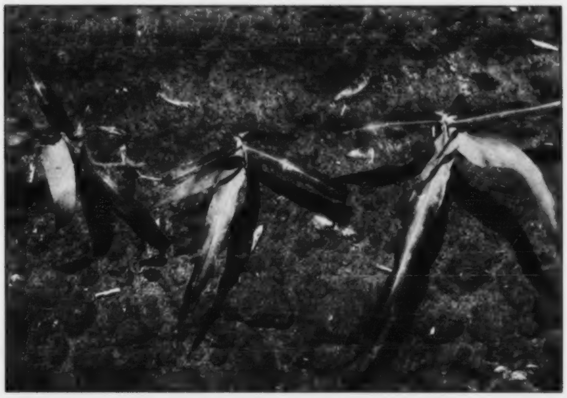


Plate 2. Purple corn. Purple leaves on corn is most often caused by cool weather stress or root injury. Occasionally, it is an indication of phosphorus deficiency.

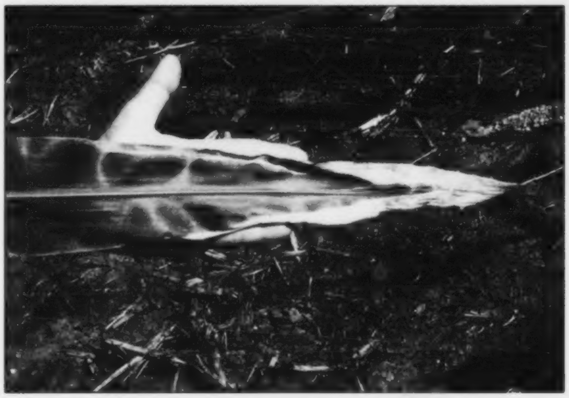


Plate 3. Potassium deficiency shows up on lower leaves first, as yellow and browning at the leaf tip, and proceeds back along the margin of the leaf.

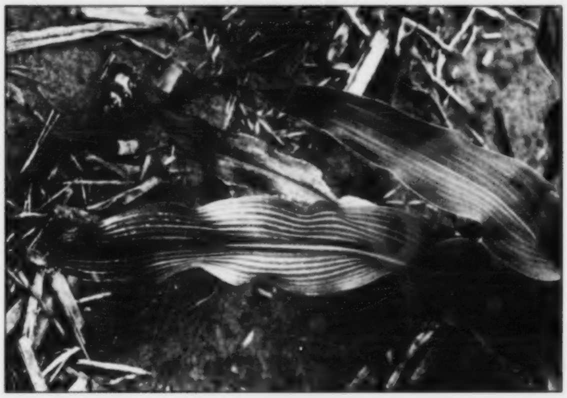


Plate 4. Magnesium deficiency appears first as yellow striping of the lower leaves. These may turn reddish-purple later as deficiency progresses.

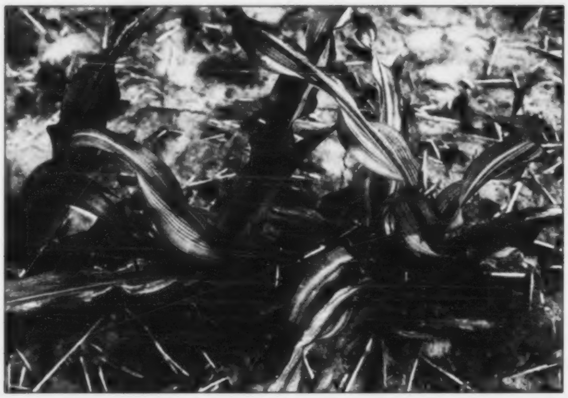


Plate 5. Zinc deficiency appears as a broad white band near the base of the leaf on younger plants.

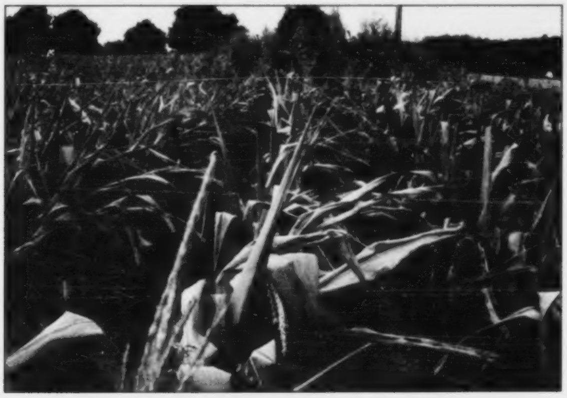


Plate 6. Moisture deficiency, or drought stress, is most critical to yield during tasselling-to-silking stages.

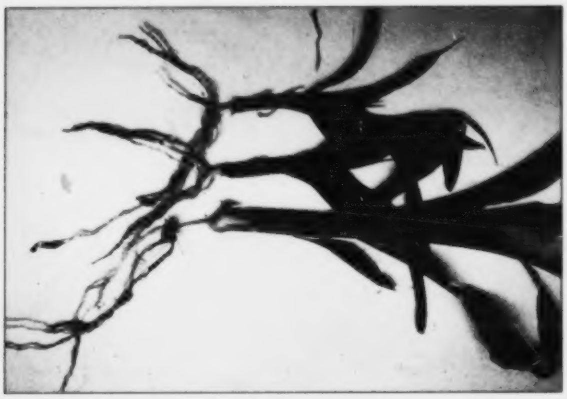


Plate 7. Uneven planting depth. Uniform seeding depth is critical to achieving uniform emergence.

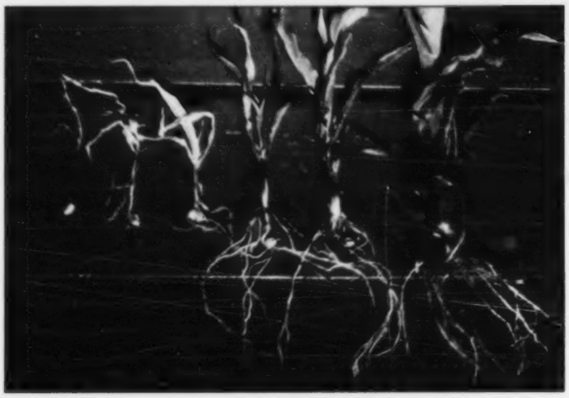


Plate 8. Fertilizer injury burns the primary root, delaying growth until secondary roots develop. Plant emergence will be uneven.

Plate 9. Frost injury on corn in mid-June. Smaller plants can recover, but growth in larger plants may be restricted by frost-injured dead tissue.

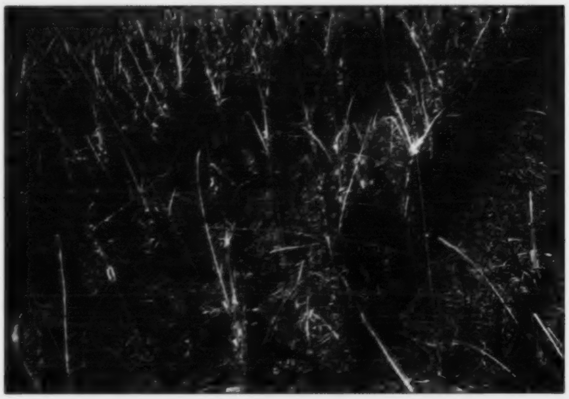


Plate 10. Hail damage is most harmful if defoliation occurs during tasselling.

Plate 11. Bird damage on corn ears.

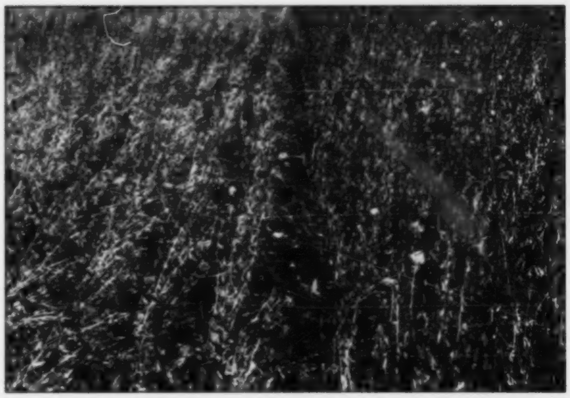


Plate 12. High seeding rates can result in lodging. On the left, a high seeding rate of 250,000 seeds/acre. On the right, a population of 200,000 seeds/acre has no lodging.

Plate 13. Lack of germination or emergence due to shallow planting into dry soil. Left side planted at 4 cm (1. 5 in.), right side at 2 cm (0. 75 in.).

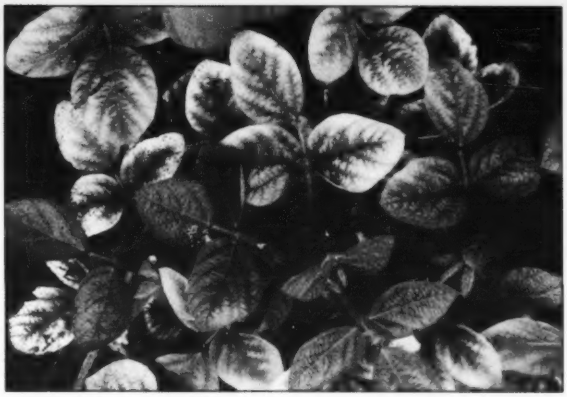


Plate 14. Potassium (K) deficiency appears as yellowing or browning of leaf margins on older leaves.

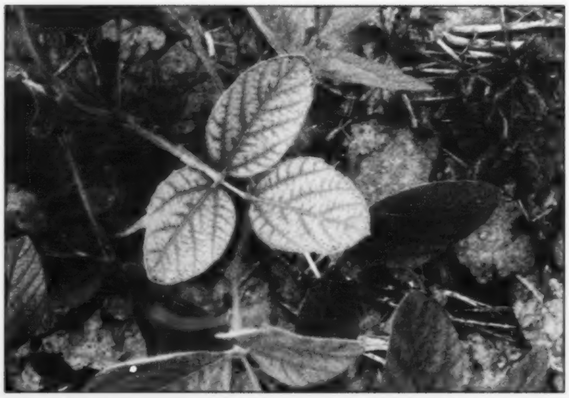


Plate 15. Manganese (Mn) deficiency. Upper leaves appear pale green to almost white with green veins.

Plate 16. Frost injury. If frost damages the growing point, but not the stem, the plant may recover by new growth emerging at the leaf axils.

Plate 17. Hail damage. Soybeans are most vulnerable to hail damage during flowering and pod fill.

Plate 18. Lightning damage occurs in small circular areas that have a clearly defined margin.

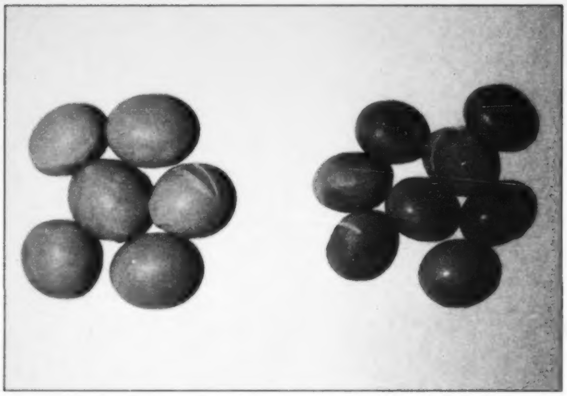


Plate 19. Mature green seed occurs when chlorophyll is not broken down during pod fill in drought-stressed plants. The right side shows mature green seed damage.

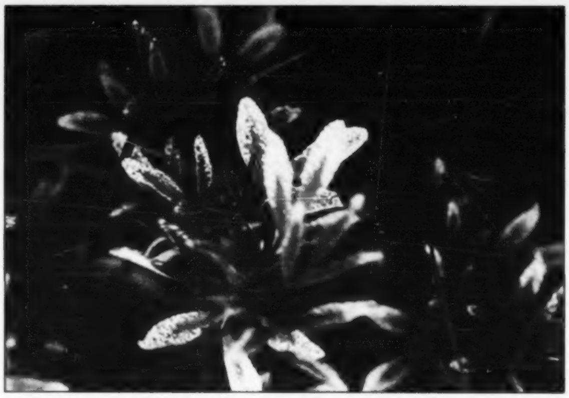


Plate 20. Potassium deficiency in alfalfa is indicated by small, light dots near margins of the leaflets.

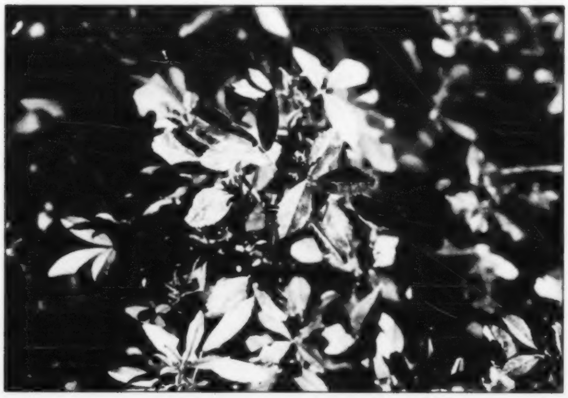


Plate 21. Boron deficiency appears on the upper leaves of alfalfa, becoming yellow to red and stunting growth.

Plate 22. Alfalfa heaving is caused by freeze/thaw cycles of early spring, lifting up the crown.

Plate 23. Corn row syndrome of winter wheat is caused by fertilizer or pesticide carryover in the rows of previous crops.

Plate 24. Lodging due to overlaps and/or excessive rates of nitrogen fertilizer.

Plate 25. UAN 28% leaf burn. Applications of 28% nitrogen fertilizer can burn leaves and reduce yields.

Plate 26. Manganese deficiency on oat looks like irregular, oval, grey spots.

Plate 27. Manganese deficiency on winter wheat (pale-yellow interveinal stripes on the leaves) occurs most frequently on high pH, sandy soils or on organic soils.

Plate 28. Frost heaving of winter wheat is caused by freeze/thaw cycles of early spring, lifting up the crown.

Plate 29. Ozone (bronzing) injury. High levels of ozone can injure the leaves and cause bronzing of the upper leaf surface.

Plate 30. Sulphur deficiency in canola results in mottling of the leaf surface, purple underside of leaves and small, pale yellow flowers.

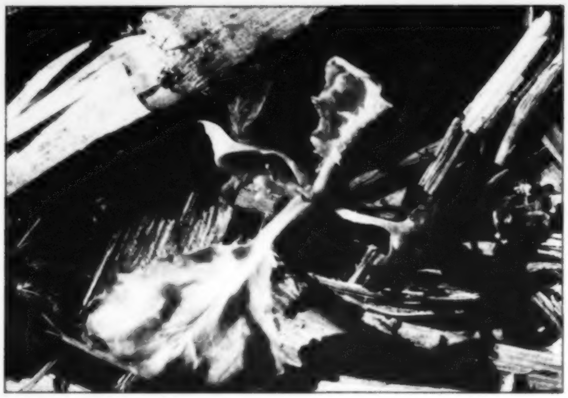


Plate 31. Canola seedlings can recover from frost if the growing point is not damaged. The growing point will remain green.

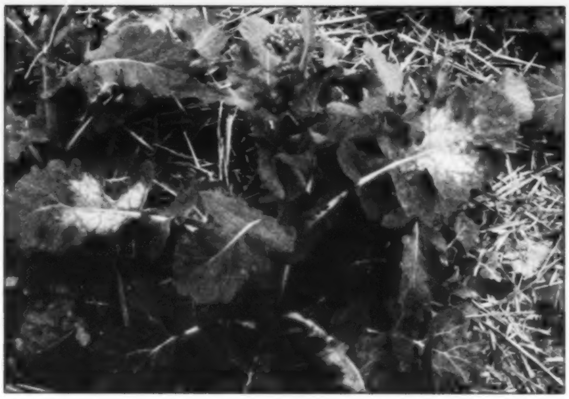


Plate 32. Cold temperature leaf injury in winter canola.

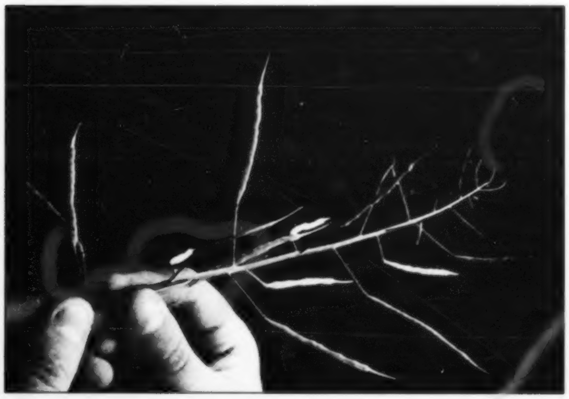


Plate 33. Heat blast. Hot temperatures during flowering (especially spring varieties) can cause heat blast and reduce seed yields.

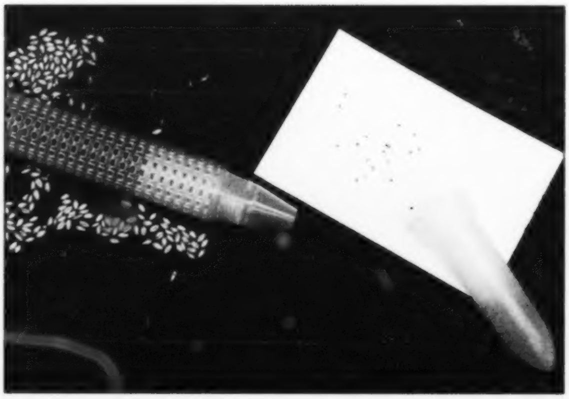


Plate 34. Insect probe for stored grain is inserted into grain to trap insects.

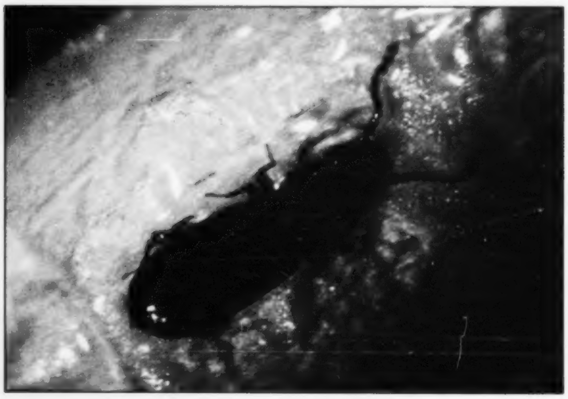


Plate 35. Rusty grain beetle adults have antennae as long as or longer than their head and thorax combined.

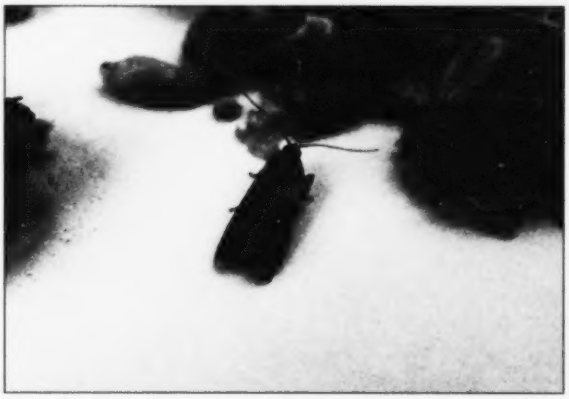


Plate 36. Indian meal moths leave webbing on top of the grain pile.

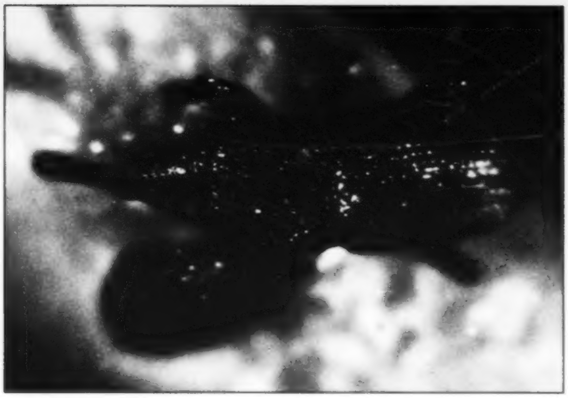


Plate 37. Granary weevil is a snout beetle that has oval pits on the surface of the thorax.

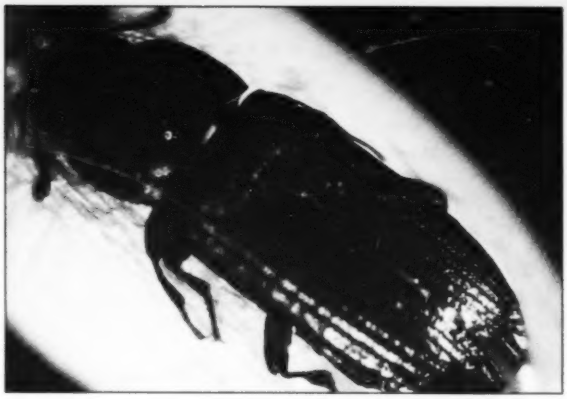


Plate 38. Lesser grain borer's head is turned downward and covered by a large hood (prothorax). A musty odour is often associated with this pest.

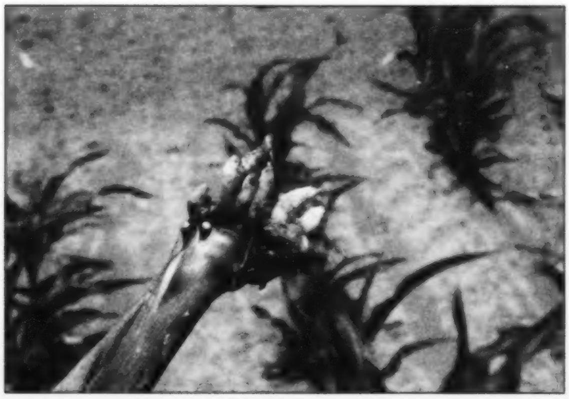


Plate 39. Prowl (pendimethalin) injury in corn causes short, thick and stunted roots.

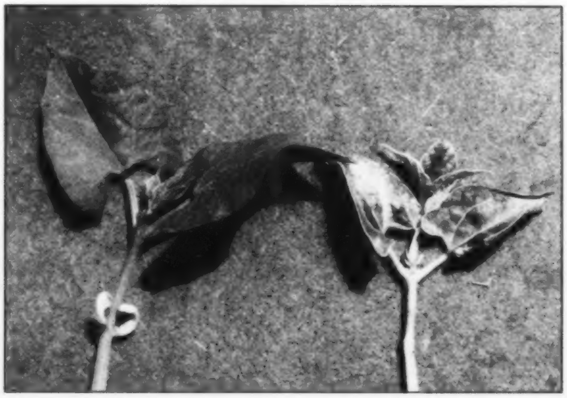


Plate 40. Frontier (demethenamid) injury to dry edible beans (right), compared to an uninjured plant (left). Yellowing of the leaf margin is an early symptom associated with the herbicide injury, which will later turn necrotic (brown).

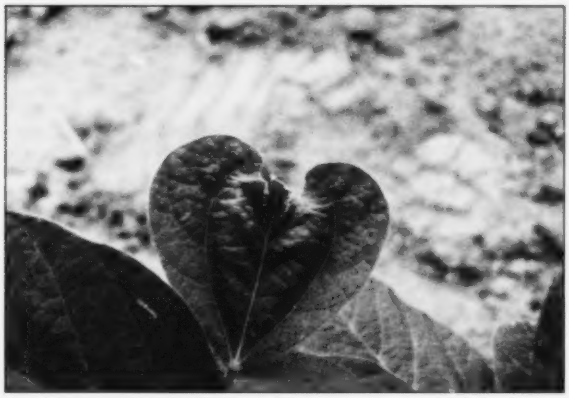


Plate 41. Dual II Magnum (s-metolachlor/benoxacor) injury in soybean, showing the characteristic "draw-string" effect that gives a heart-shaped leaf appearance.

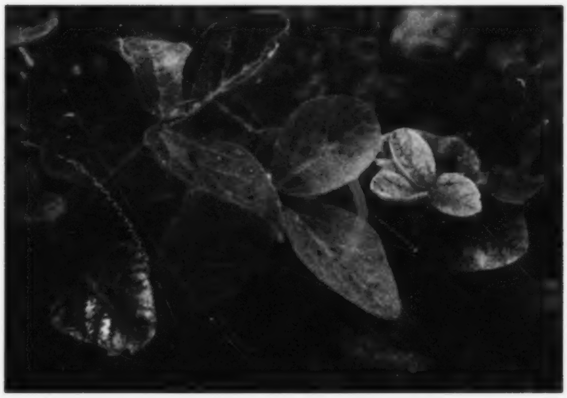


Plate 42. Soybean response to atrazine residues. Note the lower leaf margins turn yellow. Yellowing then moves to the inner part of the leaf. The yellow leaf tissue will eventually turn brown.

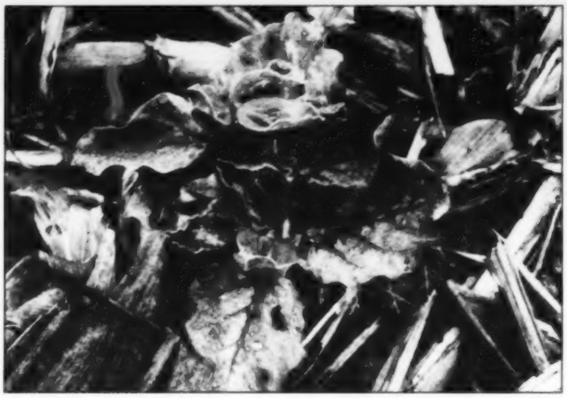


Plate 43. Soybean response to Sencor (metribuzin) "Splash." Note the severe browning that affects more of the lower leaf tissue.

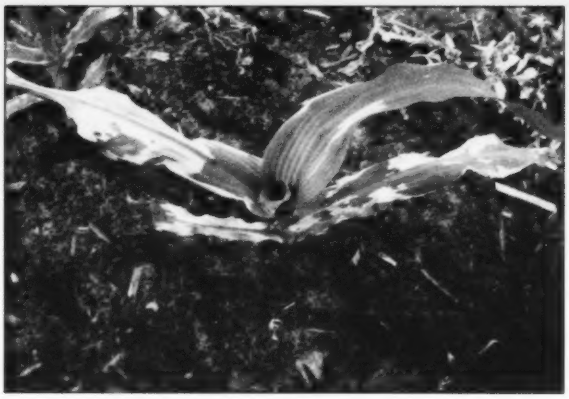


Plate 44. Pardner (bromoxynil) leaf tissue burn on corn.

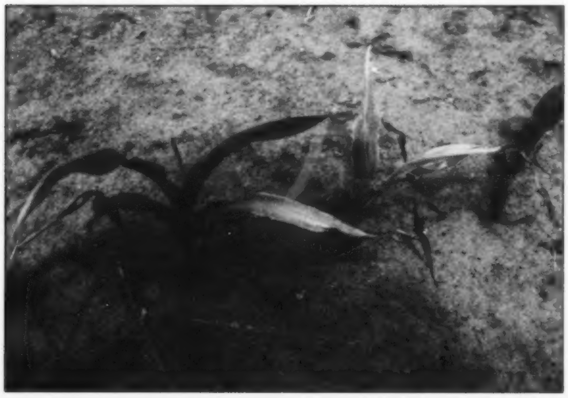


Plate 45. Reglone (paraquat) drift onto field corn. Note the severe necrosis (browning) of lower leaf tissue while new leaf tissue is unaffected.

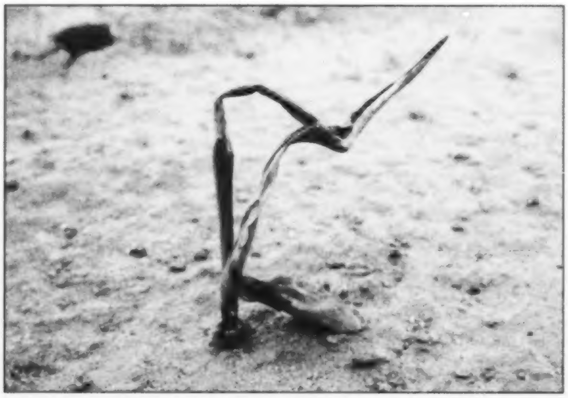


Plate 46. Corn leaf tissue response to Reflex (fomesafen). Note the severe necrosis (browning) that causes a fusing of the newest leaf tissue, obstructing normal development of subsequent vegetation.

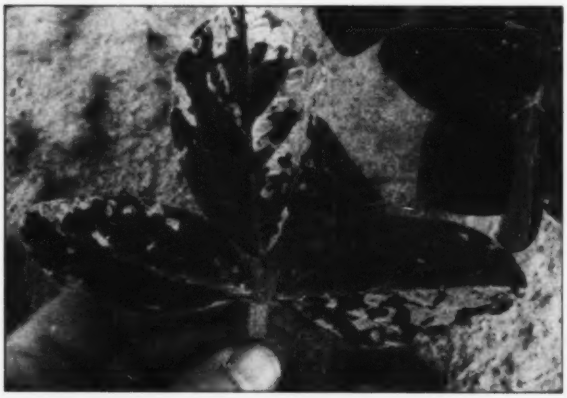


Plate 47. Surfactant injury to soybean.

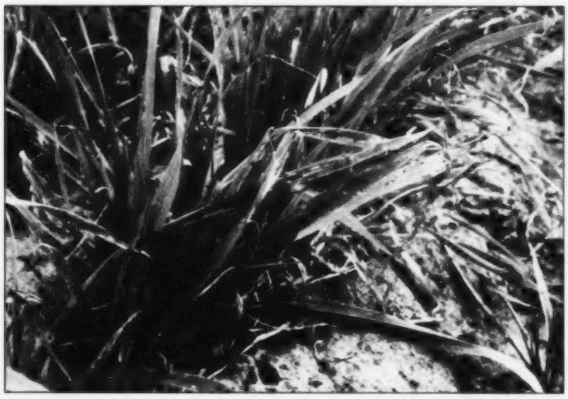


Plate 48. UAN fertilizer burn to winter wheat leaf tissue.

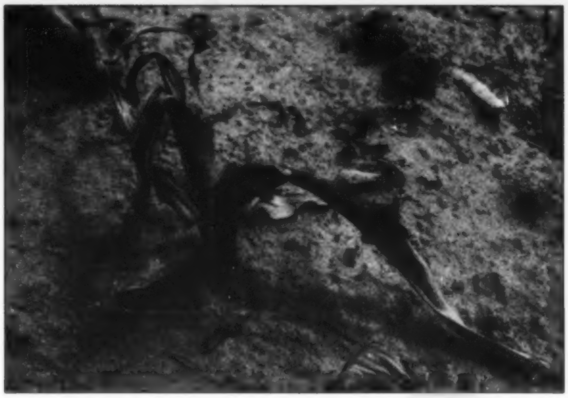


Plate 49. Corn response to Assure II off-target drift. Symptoms to the corn plant will include stunting, reddening of leaf tissue and browning of the growing point.

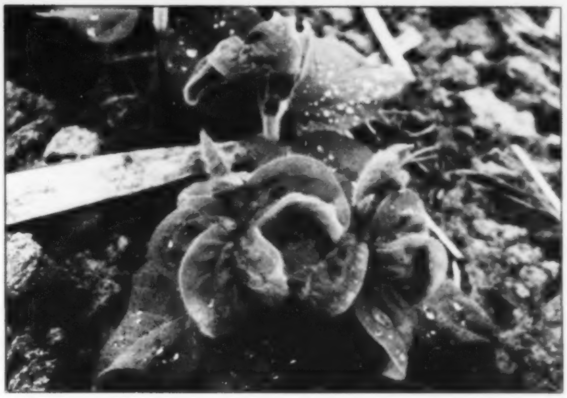


Plate 50. Classic (chlorimuron) injury to soybean. The three common symptoms of this class of herbicides are leaf distortion, yellowing of leaf tissue and browning/reddening of leaf veins on the underside of the leaf.

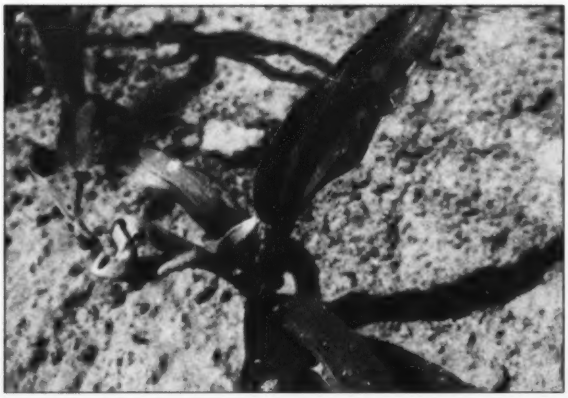


Plate 51. Corn response to Pursuit (imazethapyr) drift. Note the distortion and reddening/purpling of the leaf tissue.

Plate 52. Ulxtim, Accent or Option injury to corn where symptoms include distortion and yellowing of the new leaf tissue.

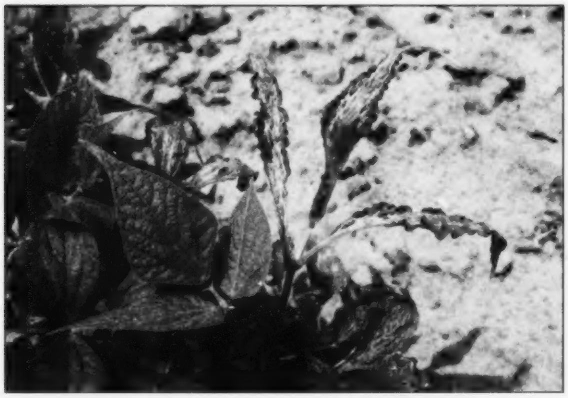


Plate 53. 2,4-D injury to dry edible beans. 2,4-D injury can often be differentiated from dicamba injury by the elongated petiole of the trifoliate leaf, the "bubbling" of leaf tissue and the narrowing of trifoliate leaves.

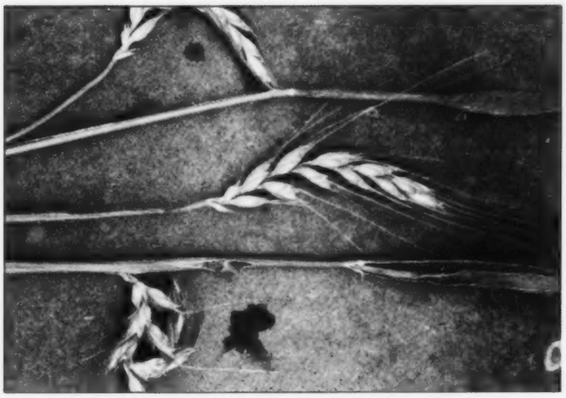


Plate 54. Twisting and distortion of winter wheat heads from an in-crop application of 2,4-D applied in the fall.

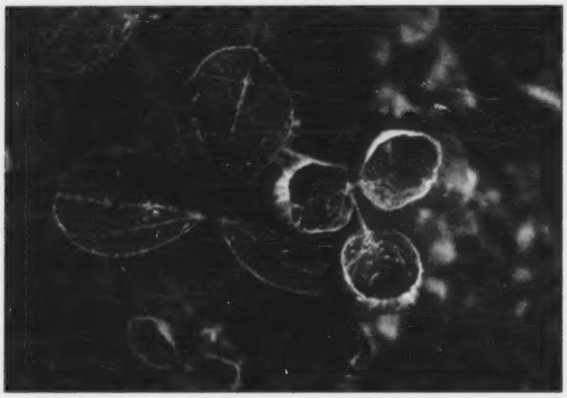


Plate 55. Soybean leaf cupping caused by off-target dicamba drift.

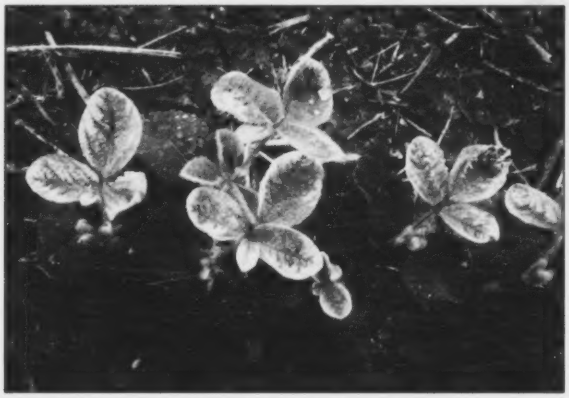


Plate 56. Glyphosate drift onto non-tolerant soybeans. Note the newest leaf tissue is yellow, a very characteristic symptom of glyphosate injury to plants.

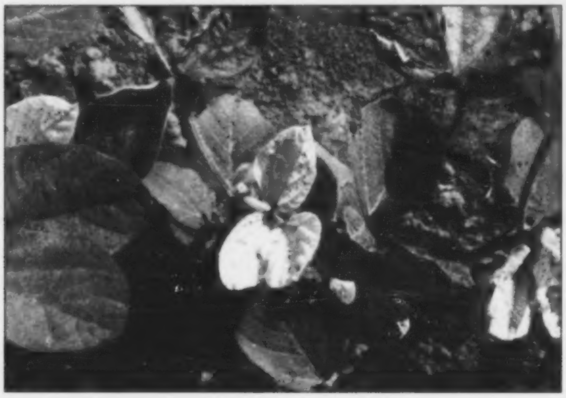


Plate 57. Soybean response to Callisto (mesotrione) drift with the characteristic "bleaching" of new leaf tissue. This tissue will then turn yellow, followed by brown.

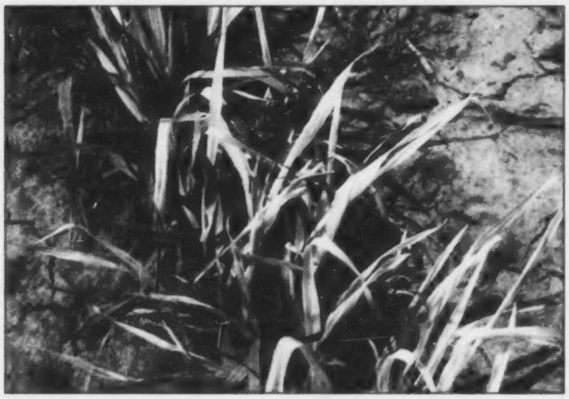


Plate 58. Bleaching of a spring cereal crop due to Command (clomazone) carryover. Leaf tissue will go from white to pinkish-purple, followed by browning. Most of the whitened leaf tissue will not make a full recovery.

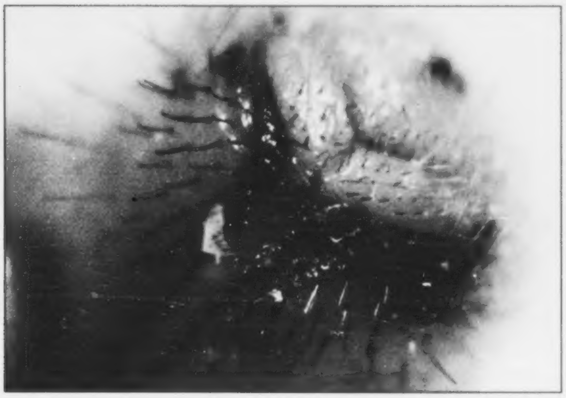


Plate 59. European chafer larvae are white with an orange-brown head and dark posterior. They are distinguished from other white grubs by the Y-pattern of the anal bristles (rasters).

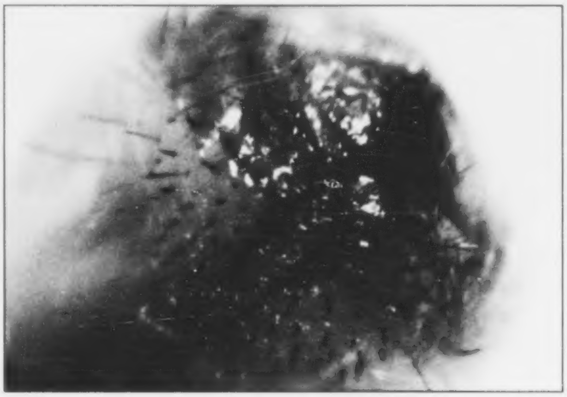


Plate 60. June beetle larvae have a raster shaped like an oval, with the two rows of rasters running parallel to each other.

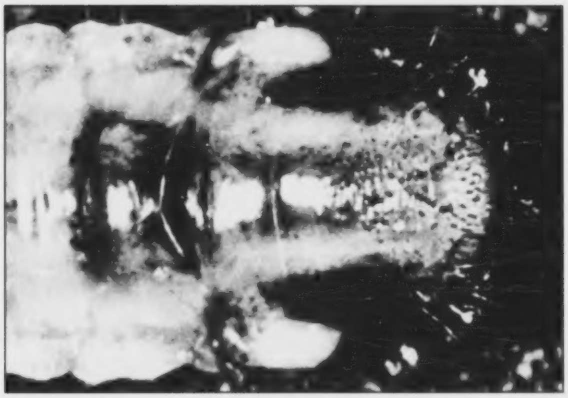


Plate 61. Japanese beetle larvae can be distinguished from other grubs by the wide, shallow, V-shaped raster pattern.

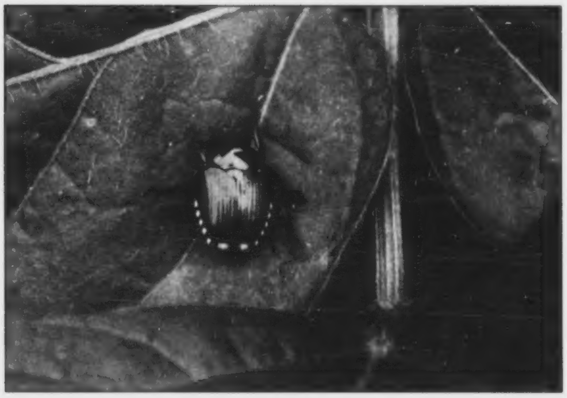


Plate 62. Japanese beetles have a bright, metallic green head with coppery wings tinged with green edges. Twelve white tufts of hair appear at the wing boundary.

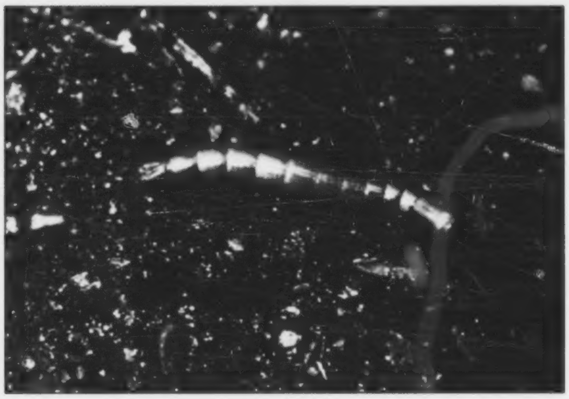


Plate 63. Wireworms have long, cylindrical, copper-brown, hardened bodies. They affect many crops, usually when following grassy crops in rotation.

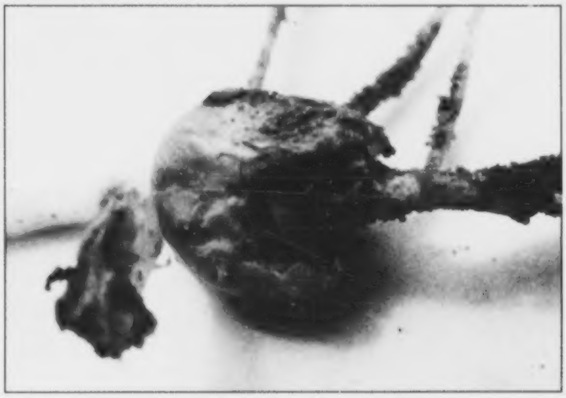


Plate 64. Seedcorn maggots are small, headless, legless larvae that burrow into germinating seeds and weaken the seedling.

Plate 65. Slugs are soft-bodied, legless and greyish or mottled. They have a gelatinous (slimy) covering that leaves trails where they have travelled.

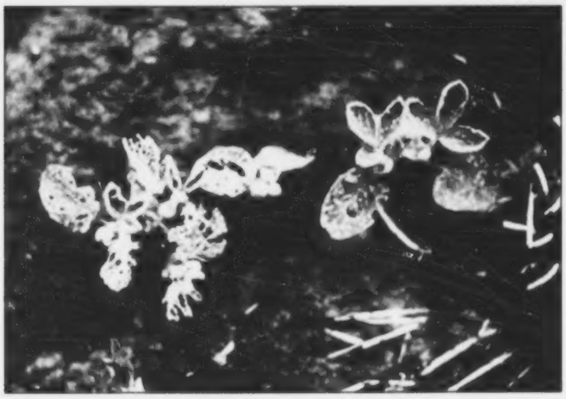


Plate 66. Foliar damage caused by slugs. Slugs feed on all parts of the plant, leaving ragged holes. Feeding on the growing point can kill the plant.

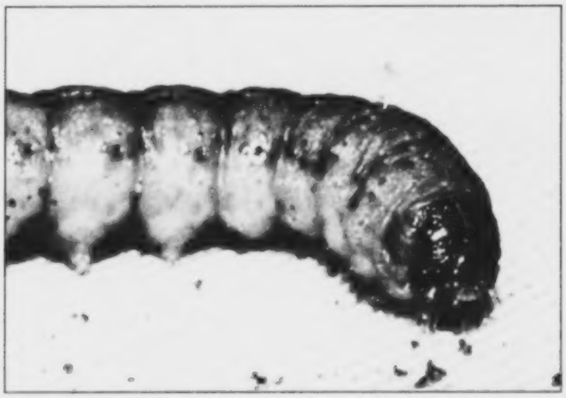


Plate 67. Black cutworm larvae are greyish-black with a pale underside. Mature larvae are about 3.5 cm (1.25 in.) long. Corn plants are cut at the soil level.

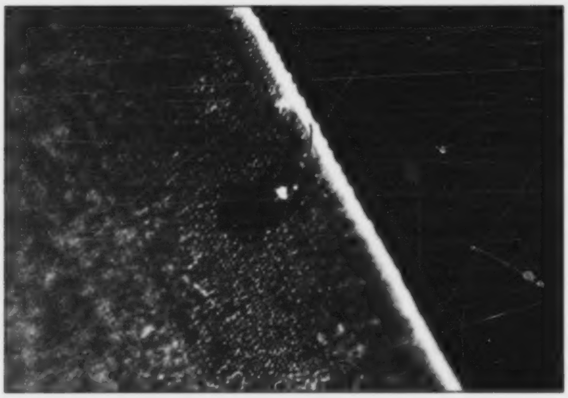


Plate 68. Corn flea beetles leave long feeding scratches running parallel to the leaf vein. These beetles are vectors of Stewart's wilt (bacterial leaf blight).

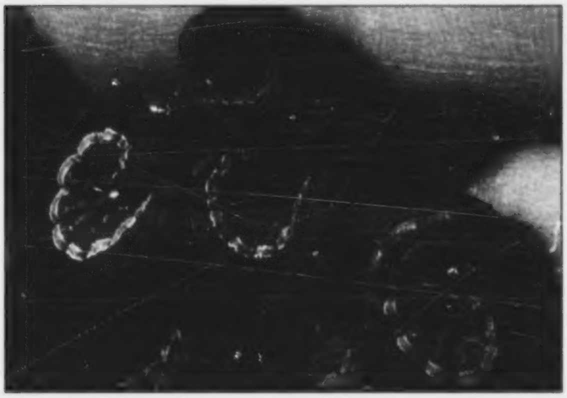


Plate 69. True armyworm larvae have black bands at the top of each proleg and a yellow-brown head with dark brown veins in a striped pattern.

Plate 70. Potato stem borer larva emerging from the base of a corn stalk. Damage is usually concentrated in border rows.

Plate 71. European corn borer egg mass. Each egg mass can have 15–40 eggs, which are layered like fish-scales.

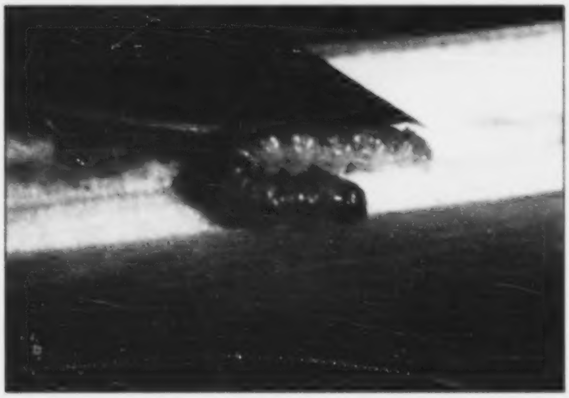


Plate 72. European corn borer larvae are cream to pink with black heads and two black spots per abdominal segment. Stalk rots can be carried in by larvae.

Plate 73. Adult European corn borer moths. Female (left) is larger and lighter in colour than the male (right).

Plate 74. Rootworm larvae are the most damaging stage, pruning roots, causing goose-necking or lodging at the base of the plant.

Plate 75. Western corn rootworm adults are yellow to green with three wavy black stripes on their back.

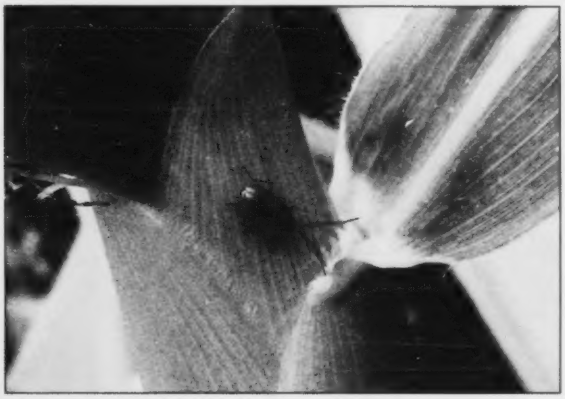


Plate 76. Northern corn rootworm adults are usually green to yellow and have no stripes.

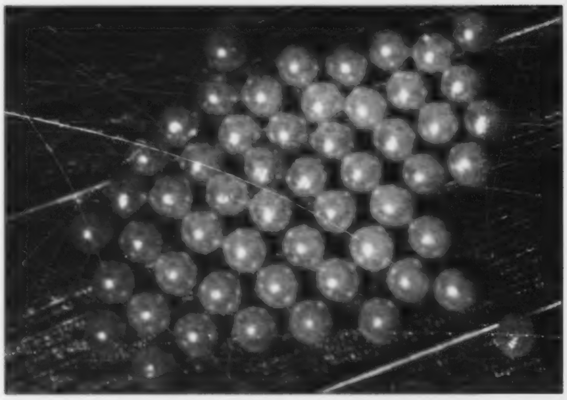


Plate 77. Western bean cutworm eggs are shaped like cantaloupe and are white when first laid. They turn purple just before the larvae hatch.

Plate 78. Western bean cutworm larvae have two broad brown bands on the pronotum (shield) behind the head.

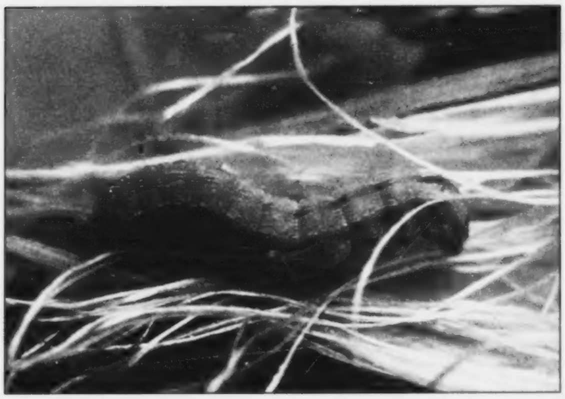


Plate 79. Corn earworm larva on corn ear. Larval feeding is usually concentrated at the tip of the ear.

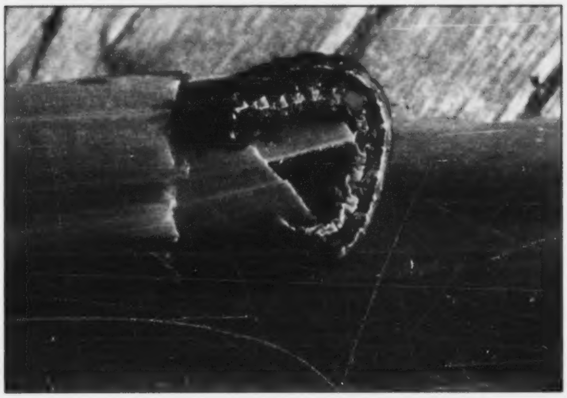


Plate 80. Fall armyworm larvae have an inverted "Y" on their dark head and have similar stripes to true armyworm, but also have elevated spots with hair.

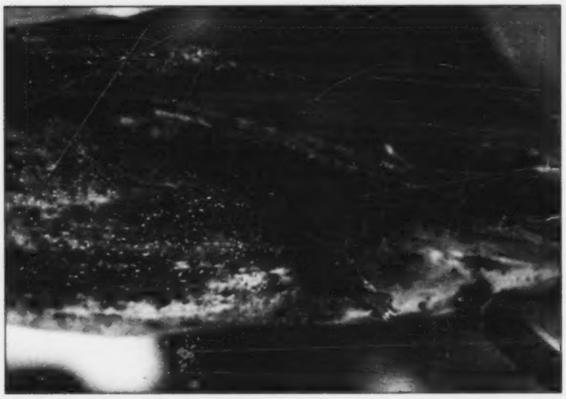


Plate 81. Corn leaf aphids clustered on corn ear. Tassels and silks may become coated with honeydew, reducing pollination success.

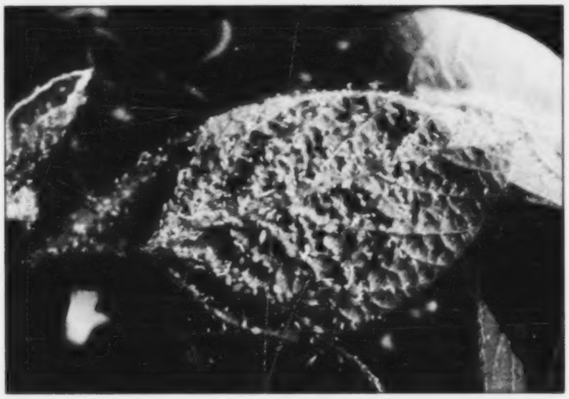


Plate 82. Soybean aphids are small, pale green to yellow and may be winged or wingless. They can be found on the underside of leaves and stems.

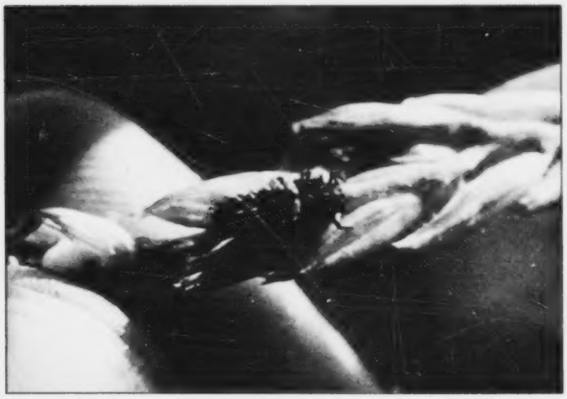


Plate 83. Ladybird beetle larvae are a natural enemy of the soybean aphid.

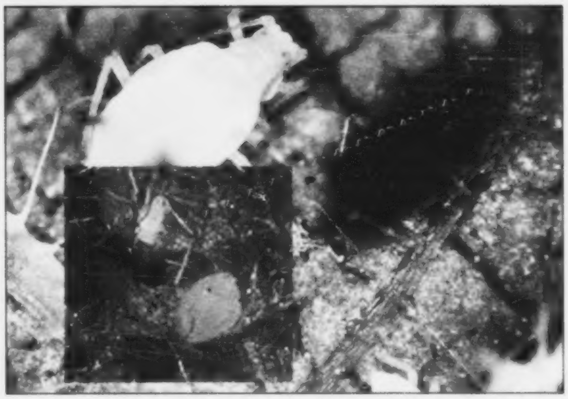


Plate 84. Black mummies (right) are the result of the aphids being parasitized by parasitic wasps (inset). These are just one of the many natural enemies of soybean aphid.

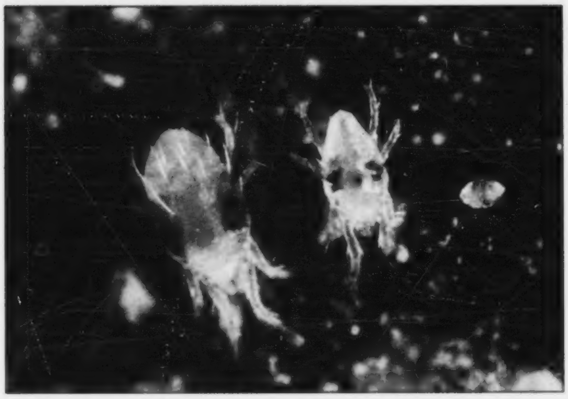


Plate 85. Two-spotted spider mites are barely visible to the naked eye. Adults are eight-legged, yellowish-brown, with two dark spots.

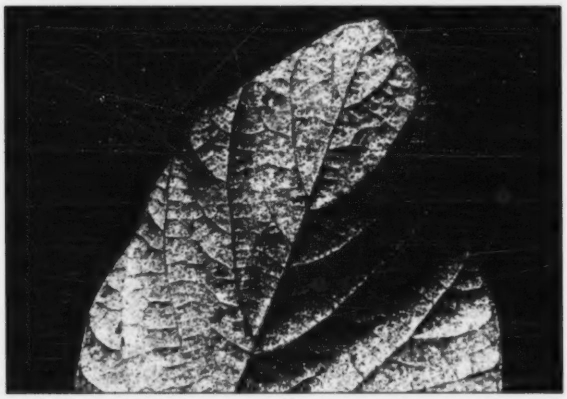


Plate 86. Spider mite infestations tend to start from the field's edge, with infested leaves turning brown and dropping off the plant.

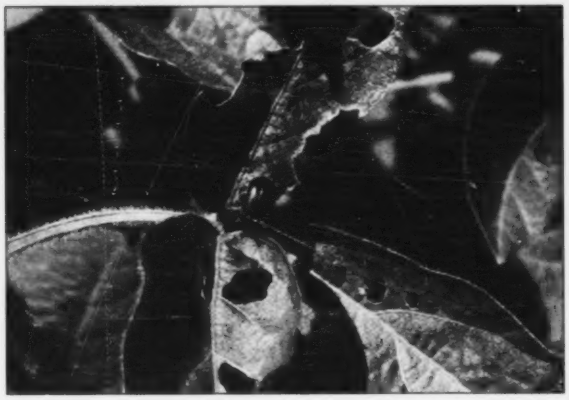


Plate 87. Bean leaf beetle adults vary in colour, but always have a small black triangle visible behind the head. They may or may not have four spots.

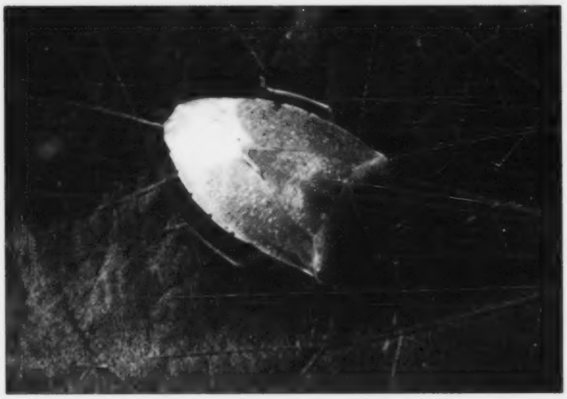


Plate 88. Green stink bug adult. Stink bugs pierce the pods and suck on the seed, causing the seed to shrivel and dimple.

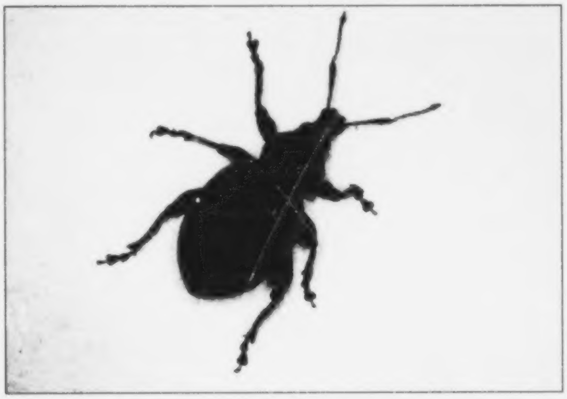


Plate 89. Alfalfa snout beetle adults are approximately 12 mm (½ in.) long and cannot fly.

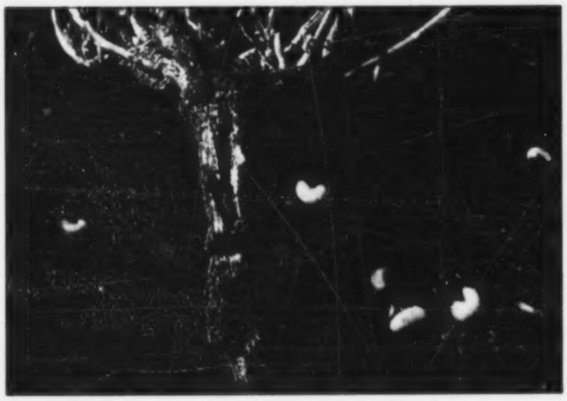


Plate 90. Alfalfa snout beetle larvae girdle the taproot or gouge its surface, leaving deep spiral grooves. Larvae are white and legless and have a reddish-brown head.

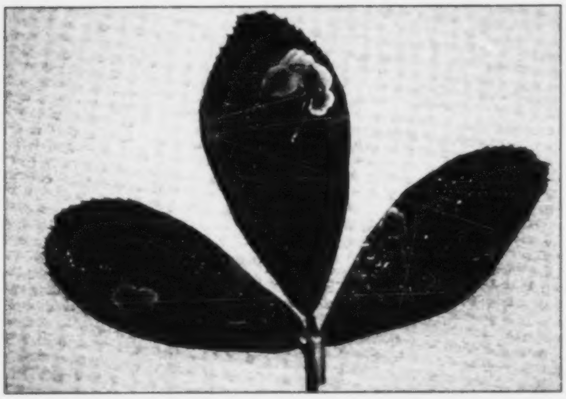


Plate 91. Alfalfa blotch leafminer larvae feed inside the leaflet, creating tunnels or mines between the top and bottom layers of the leaf.

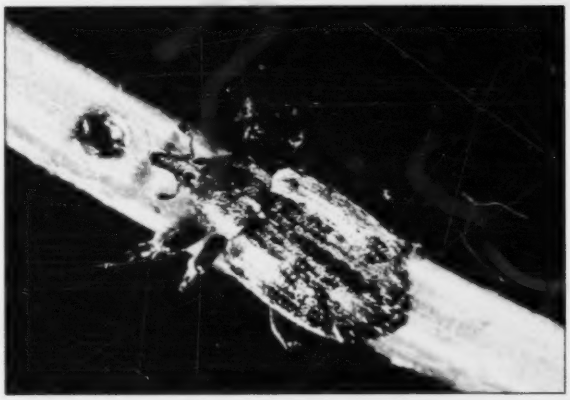


Plate 92. Alfalfa weevil adults are about 8 mm long. Note the dark stripe running along the back.

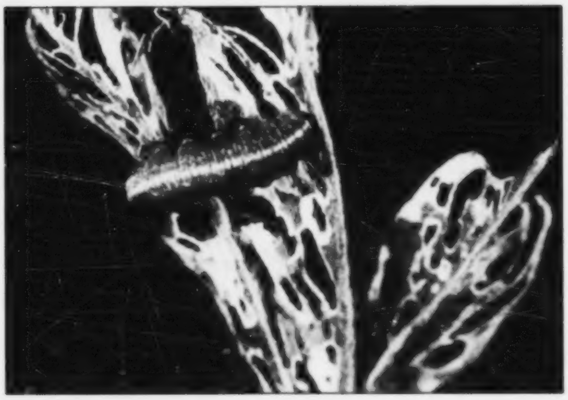


Plate 93. Alfalfa weevil larvae feed on leaves, causing skeletonization. Note that larvae have black heads.

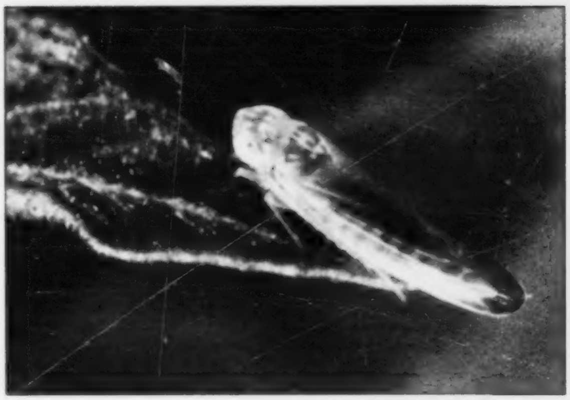


Plate 94. Potato leafhoppers are pale green, wedge-shaped, winged insects. Immature nymphs are smaller and wingless.

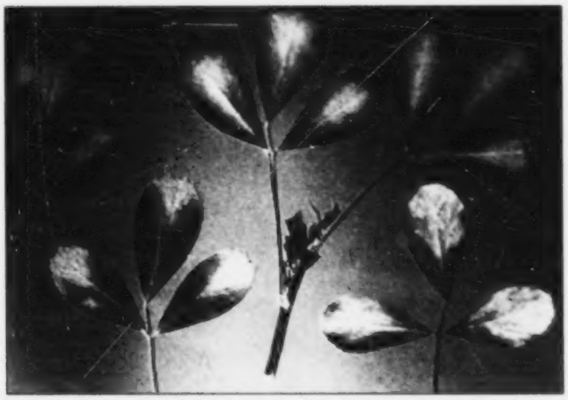


Plate 95. Potato leafhopper injury, "hopper burn," is most severe in new seedlings and in young growth.

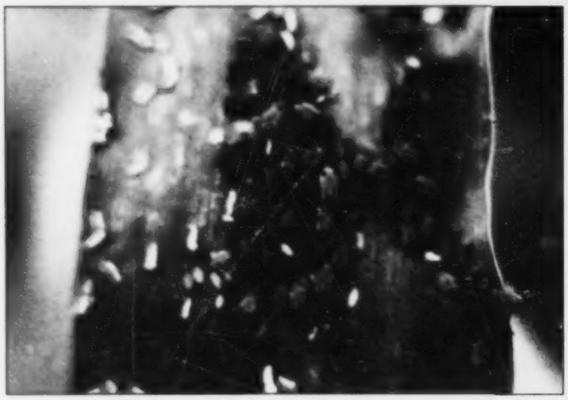


Plate 96. Bird cherry-oat aphids are dull, olive-green with patches of red-orange near the rear of the abdomen.

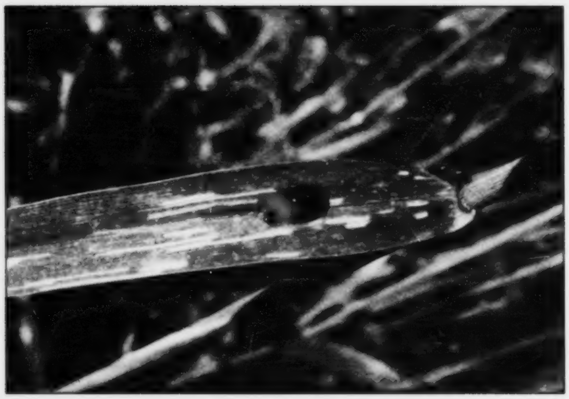


Plate 97. Cereal leaf beetle larvae are yellowish, but this colour is obscured by a black deposit of fecal material, making them slug-like in appearance.

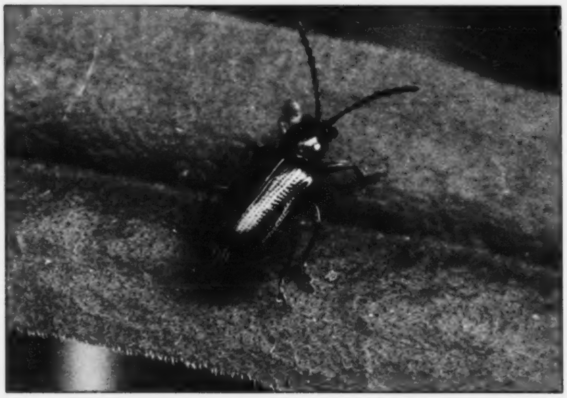


Plate 98. Cereal leaf beetle adult is metallic, blue-green with a reddish-orange head and legs.

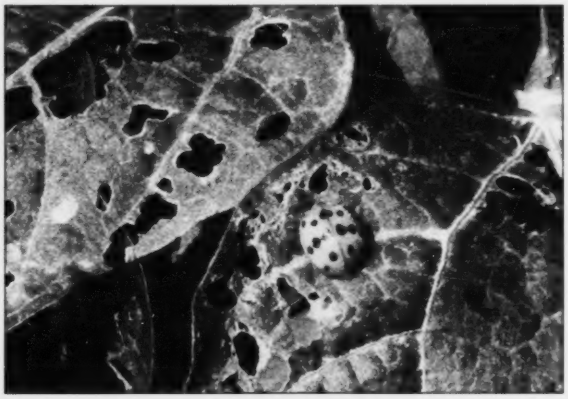


Plate 99. Mexican bean beetle adult. The beetles have 16 small black spots on their coppery-red back. Larvae have black-tipped spines along their back.

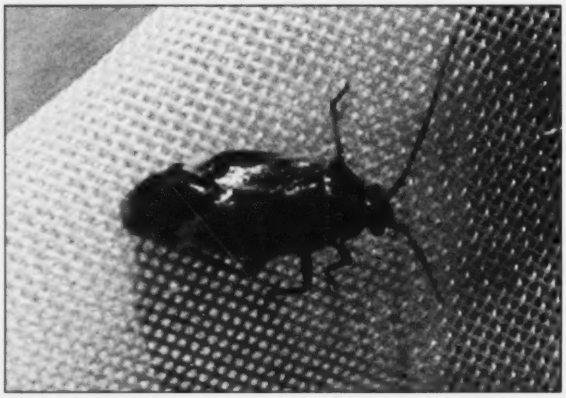


Plate 100. Tarnished plant bugs are mottled, yellowish- to reddish-brown, and have a small triangle shape on their back.

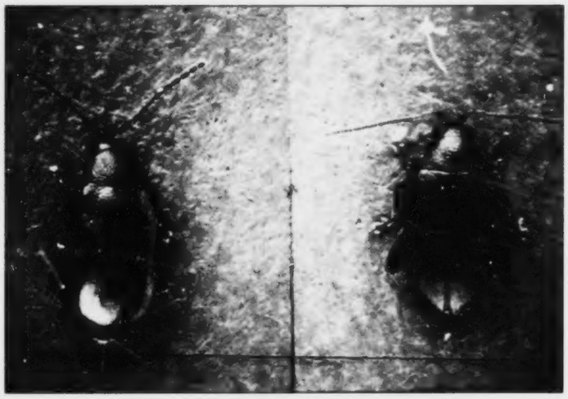


Plate 101. Striped (left) and crucifer flea beetle adults. Flea beetle injury can be severe during the first three weeks after the emergence of spring canola.

Plate 102. Cabbage seedpod weevil is ash-grey to black and has a snout that resembles an elephant's trunk.

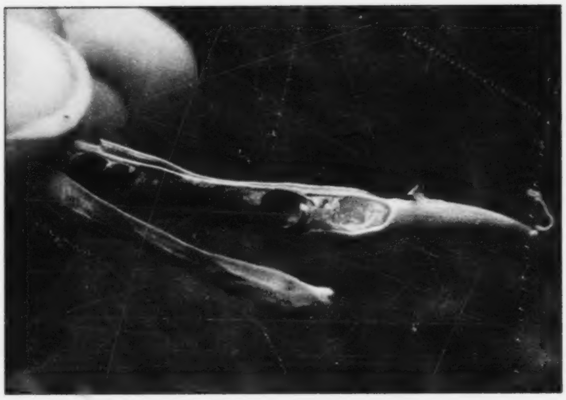


Plate 103. Cabbage seedpod weevil larvae hatch inside the canola pod and feed directly on the seed, each consuming three to five seeds.

Plate 104. Swede midge damage to a young plant prior to stem elongation can result in no racemes, flowers or pods being produced.

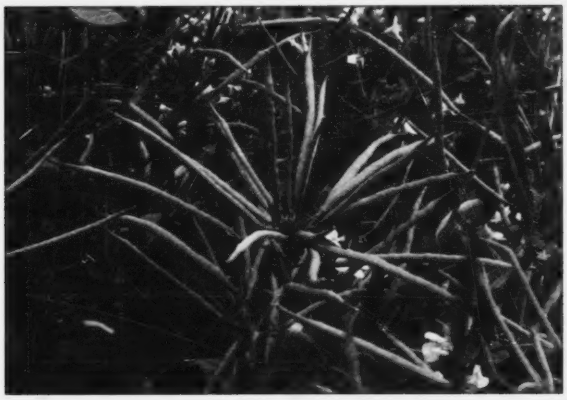


Plate 105. Swede midge injury to plants already bolted results in all pods forming from injury site, causing a bouquet of pods. Yield is not impacted in this case.

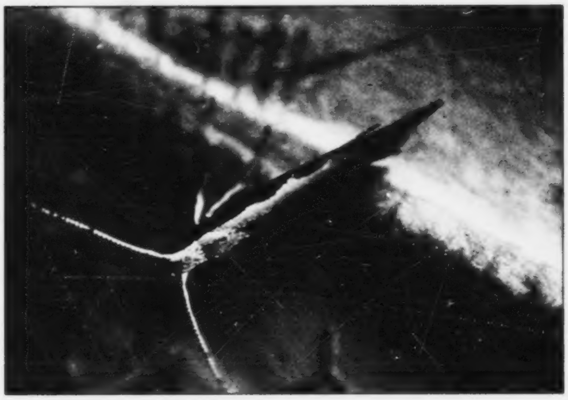


Plate 106. Diamondback moth adult is best identified by the white, diamond-shaped markings along its back when the wings are at rest.

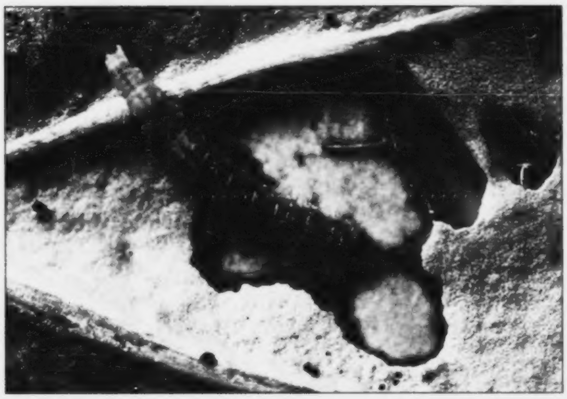


Plate 107. Diamondback moth larvae are light green to yellowish-green, with a brown head. Larvae will wiggle backwards when disturbed.

Plate 108. Anthracnose affects both leaves and stalks. The main symptoms are leaf spots, top dieback and stalk rot.

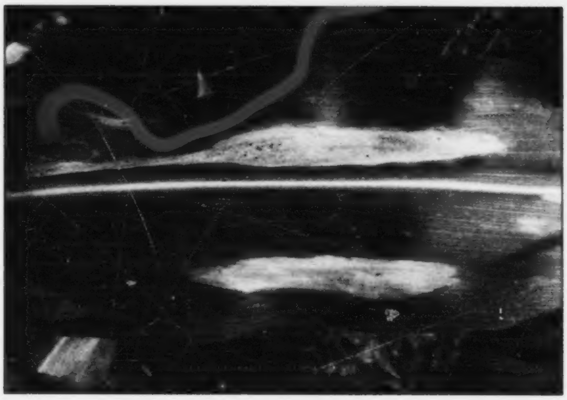


Plate 109. Northern corn leaf blight showing long, elliptical, greyish-green or tan streaks.

Plate 110. Northern leaf blight on a susceptible variety (left) and a resistant variety (right), showing fewer symptoms.

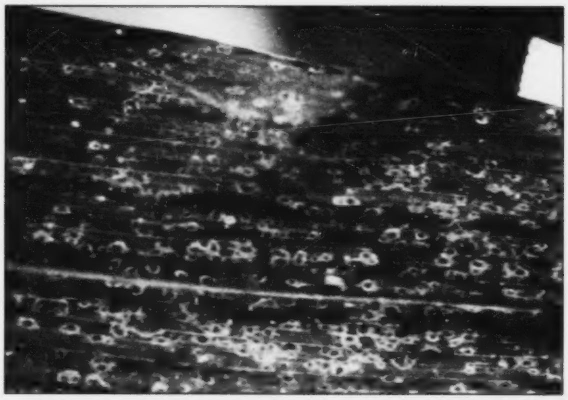


Plate 111. Eyespot causes round or oval leaf spots with a tan/brown centre, a brown or purple margin, and a translucent yellow halo when held up to the sun.

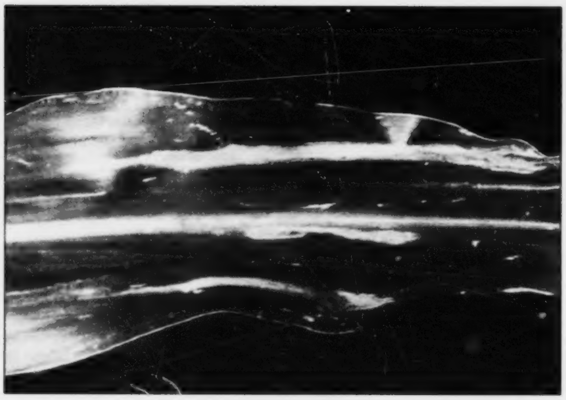


Plate 112. Stewart's wilt (bacterial leaf blight) occurs after tasselling. Wilt phase occurs at V2–V4 growth stage. Corn flea beetle is a vector of Stewart's wilt.

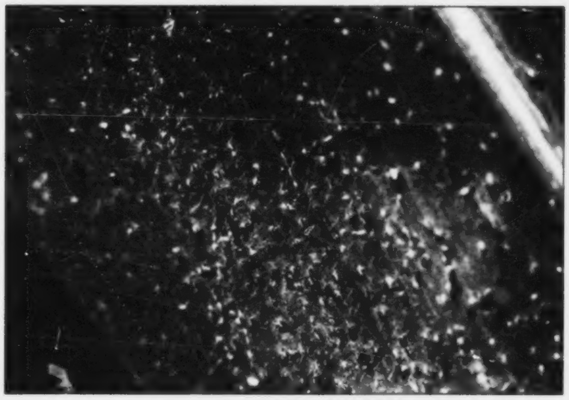


Plate 113. Common rust symptoms range from yellow flecks to red pustules.

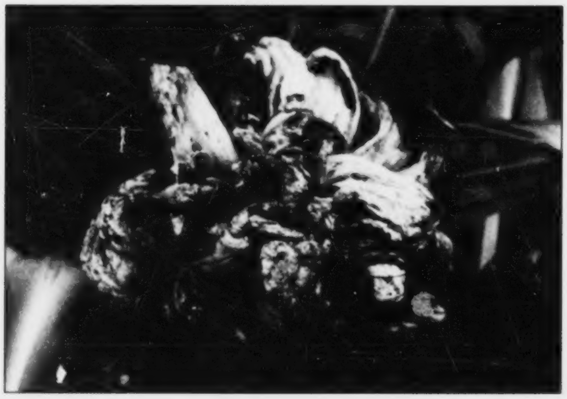


Plate 114. Common smut incidence increases where plants have been wounded.

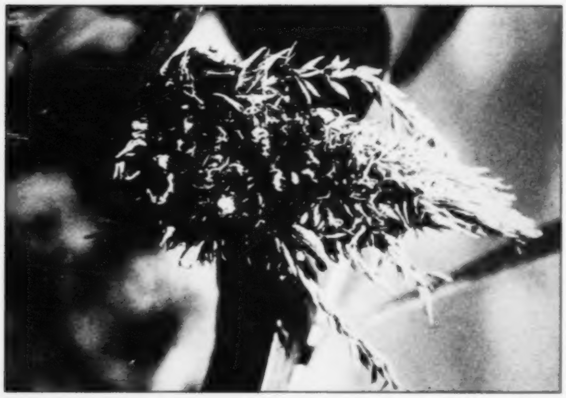


Plate 115. Head smut can occur on the ears or tassels of corn.

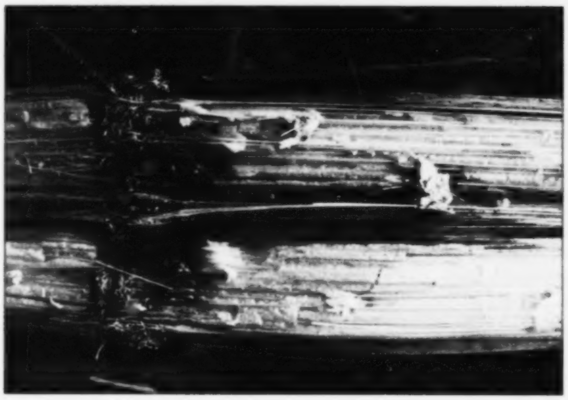


Plate 116. Anthracnose stalk rot. Internal corn stalk tissue is often discoloured (black), and the pith is rotted.

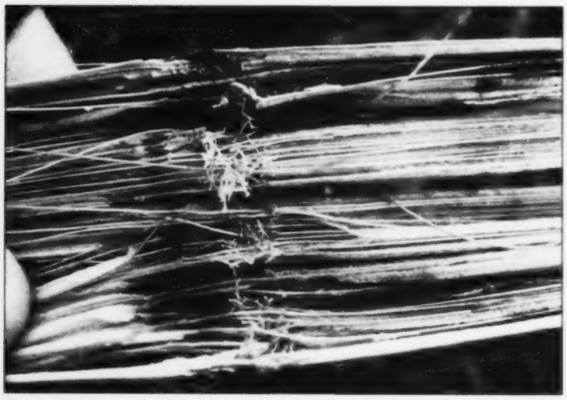


Plate 117. Gibberella stalk rot. Inside of stalk is shredded and characteristically red.

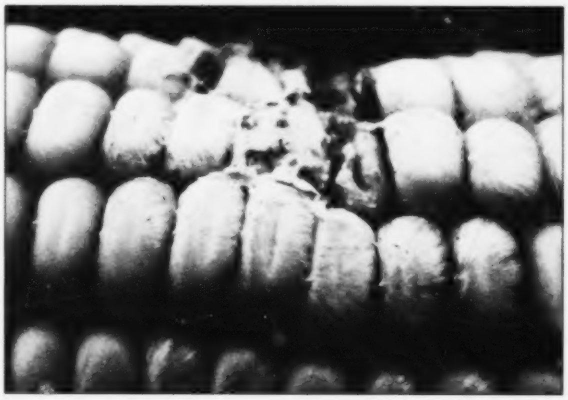


Plate 118. Fusarium ear rot. Note the white fungal growth and the "starbursting" on the kernels.

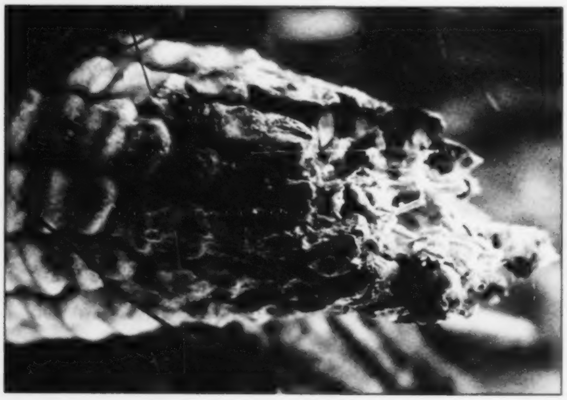


Plate 119. Gibberella ear rot infection usually occurs from the tip down. Note the pink-to-red colour.

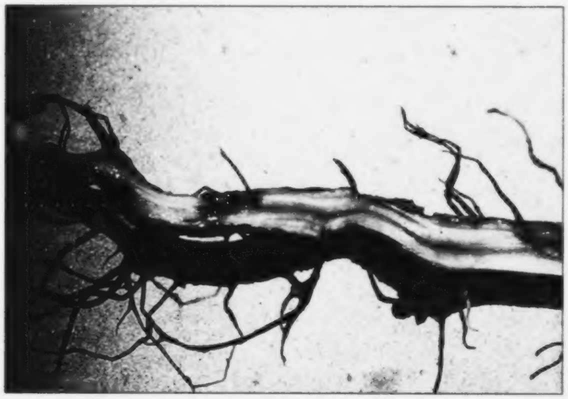


Plate 120. Fusarium root rot causes a brown discolouration of the internal root tissue.

Plate 121. Phytophthora root rot causes water-soaked lesions on seedlings and purple or dark-brown discolouration of the stem. The symptoms begin at the soil line and progress into the lower nodes.

Plate 122. Rhizoctonia root rot causes reddish lesions on the stem at or just below the soil line.

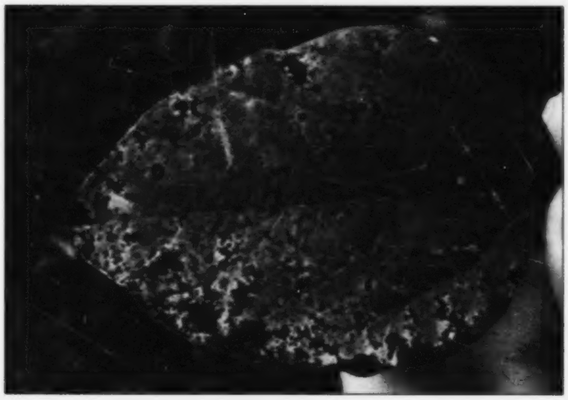


Plate 123. Septoria brown spot symptoms begin early in the season with varying sizes of brown spots beginning on the lower leaves. Infected areas turn yellow quickly, and leaves will fall to the ground.

Plate 124. Plants infected with soybean cyst nematode can be stunted, with yellowish leaves, frequently in circular patterns in the field.

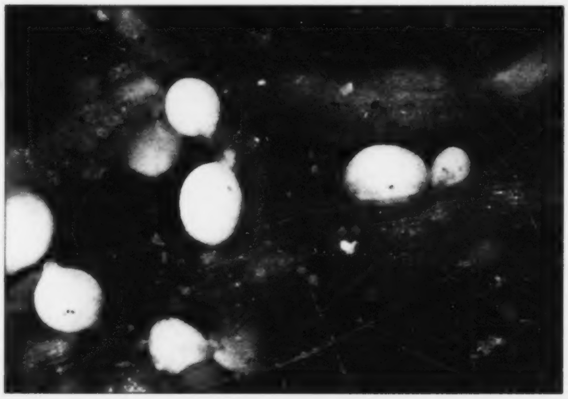


Plate 125. Soybean root with SCN cysts. Yellow-brown, lemon-shaped cysts (pin-head size) are produced on the roots of plants infected with soybean cyst nematode.

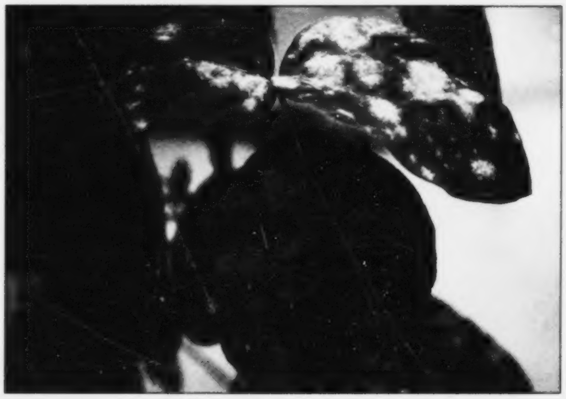


Plate 126. Powdery mildew appears as a white powder on the upper surface of the leaf.

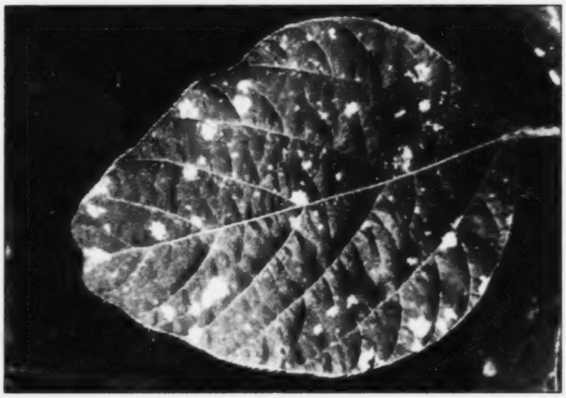


Plate 127. Downy mildew appears as yellow-to-brown spots on the leaf with pale blue-to-grey mildew on the lower leaf surface.

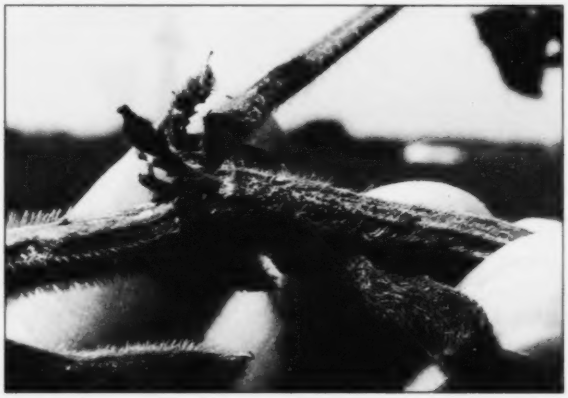


Plate 128. Stem canker causes plants to wilt suddenly. The plants have brownish-red lesions near lower nodes.

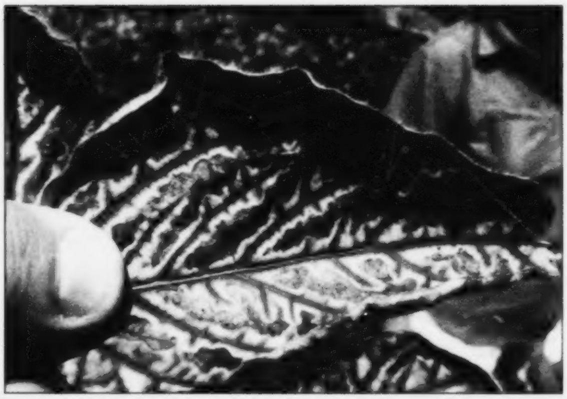


Plate 129. Plants infected with sudden death syndrome wilt and die quickly. Interveinal chlorosis and necrosis of upper leaves may occur.

Plate 130. Leaves infected with Asian soybean rust have a mottled yellow appearance that often begins on the lower leaves and moves up the plant.

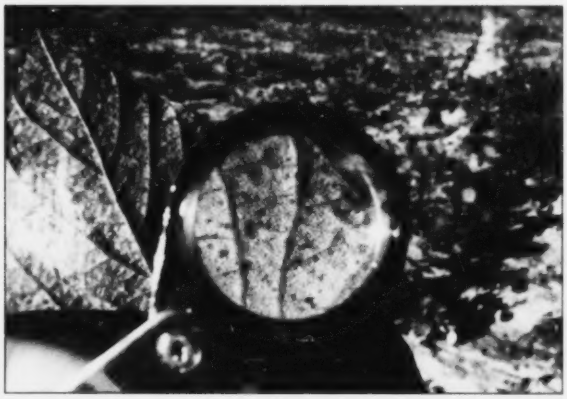


Plate 131. Asian soybean rust produces small, tan-to-dark brown or reddish-brown raised lesions where the spores are produced. A hand-lens will assist in distinguishing soybean rust from other foliar diseases.

Plate 132. Asian soybean rust can be managed effectively through scouting and a well-timed fungicide application. The left side of the field was untreated; the right side had a fungicide application.

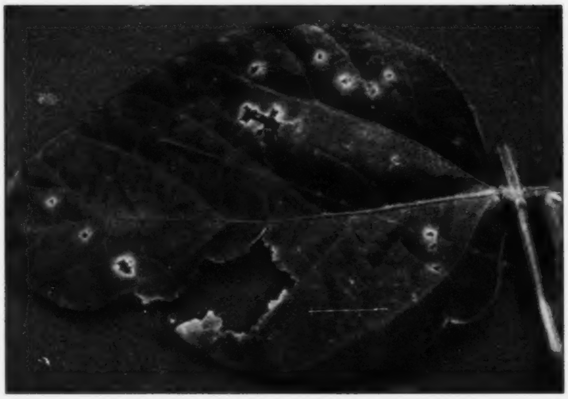


Plate 133. Bacterial leaf blight infection produces a distinctive yellow halo around the lesion, and the leaves often have a ragged appearance (tear or rip).

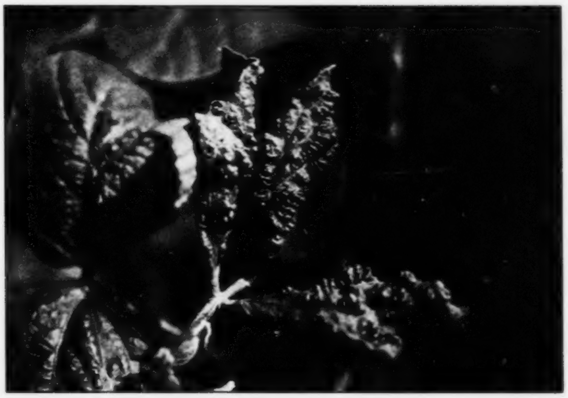


Plate 134. Soybean mosaic virus symptoms include distorted and puckered leaves. Plants may be stunted. Soybean aphids are vectors of this disease.

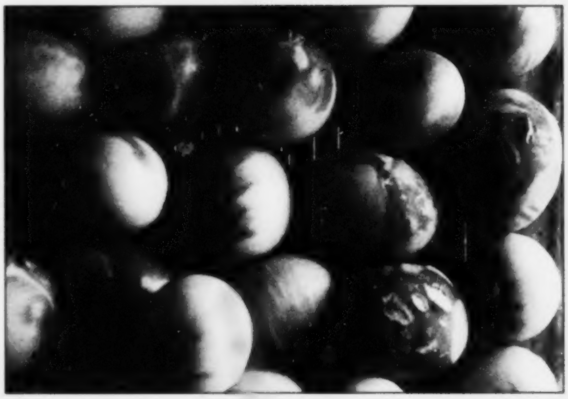


Plate 135. Soybean mosaic virus can cause brown or black discolouration of the seed and streaks near the hilum.

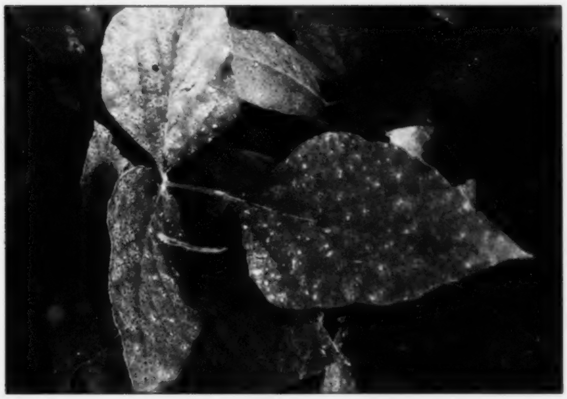


Plate 136. Frog-eye leaf spot foliar lesions have a red/brown border with a tan centre that may disintegrate, leaving holes in the centre of the lesions.

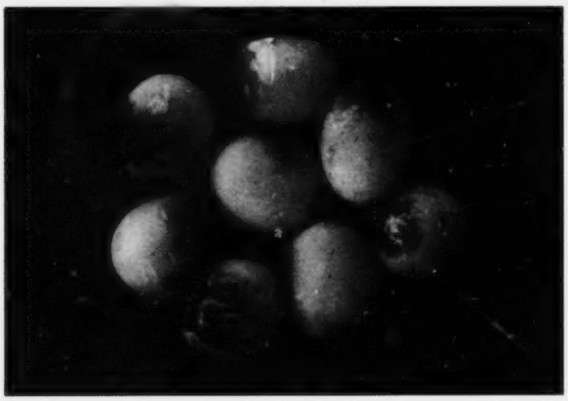


Plate 137. Distinctive purpling or staining of seed due to cercospora leaf blight infection (leaves often have a purple discolourization as well).

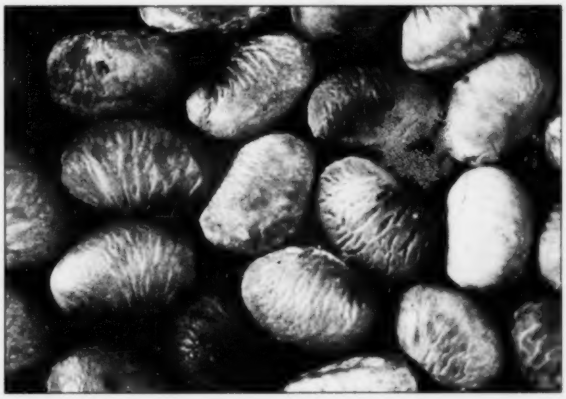


Plate 138. Phomopsis seed mould causes fine cracks and mould, starting near the hilum, reducing quality and seed vigour.

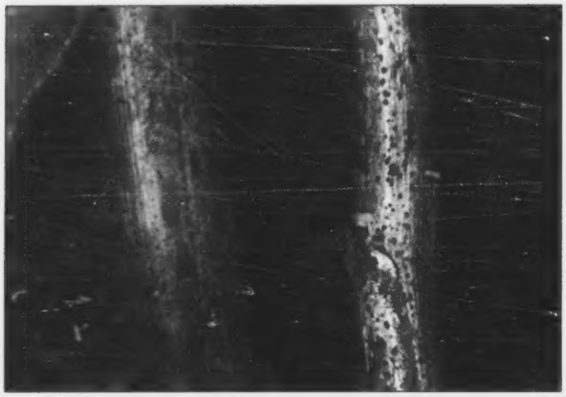


Plate 139. Phomopsis pod and stem blight symptoms include small, black, raised dots or bumps arranged in rows or islands on the stem.

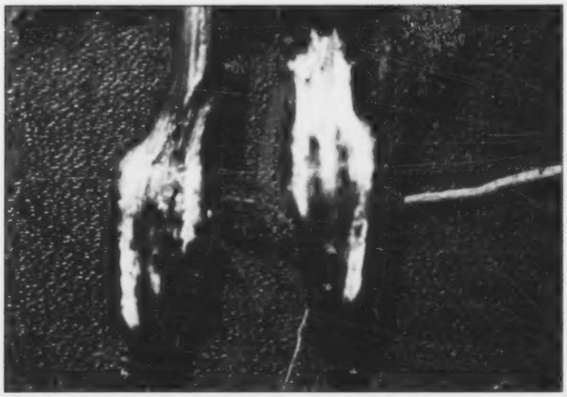


Plate 140. Phytophthora root rot infection begins as the plants emerge. Infected seedlings are stunted and begin to wilt.

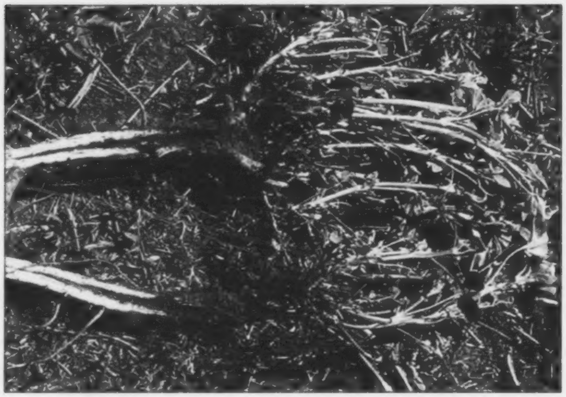


Plate 141. Fusarium root rot appears as rusty, dark brown strands in the xylem of the root.

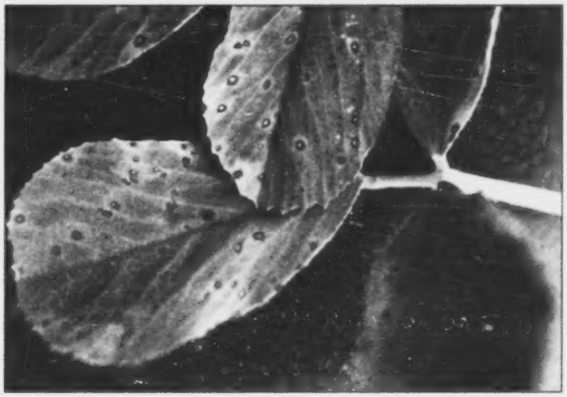


Plate 142. Leptosphaerulina (lepto) leaf spot starts as small dark spots that enlarge until spots join together. Spots will have a tan centre and a yellow halo.

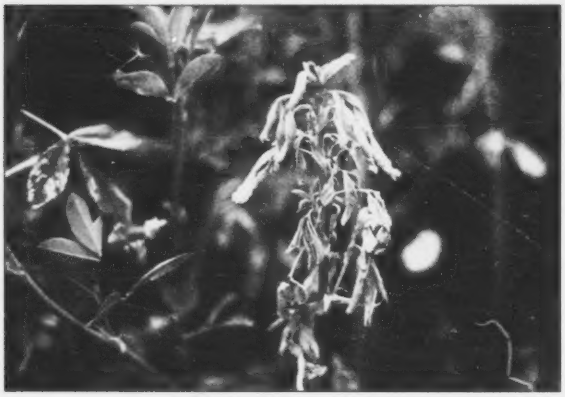


Plate 143. Verticilllium wilt initially affects each stem, causing stems to wilt, curl inward and become bleached. Growth is stunted.

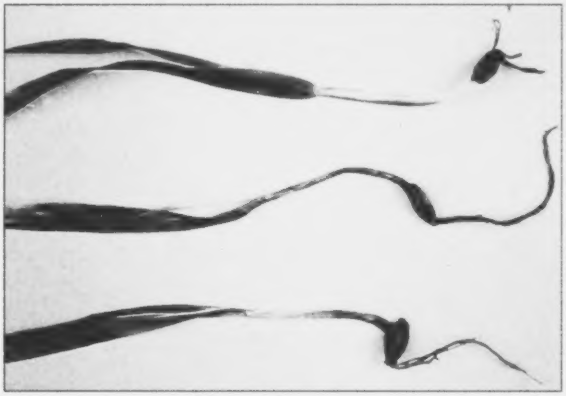


Plate 144. Seedling blights are caused by several organisms. Many seedlings fail to emerge, or emerge looking yellow with brown or red-brown rot on the lower stem.

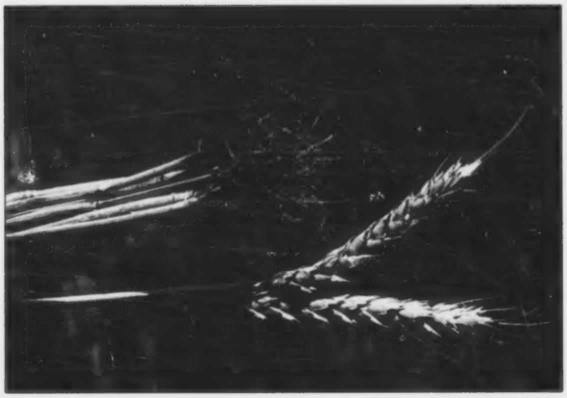


Plate 145. Take-all is noticeable at heading. Head, stem and leaves all become bleached due to this root disease.

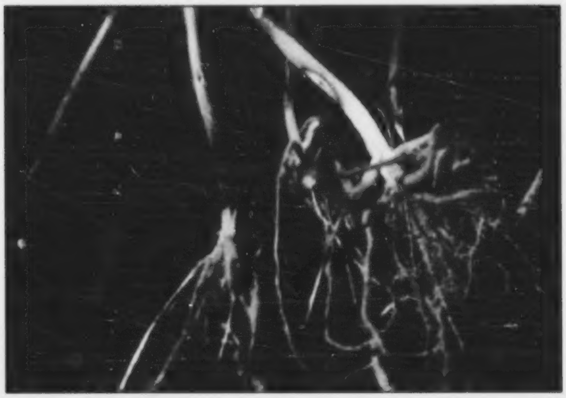


Plate 146. Eyespot produces elliptical, eye-shaped lesions on the lower internode near the soil line.

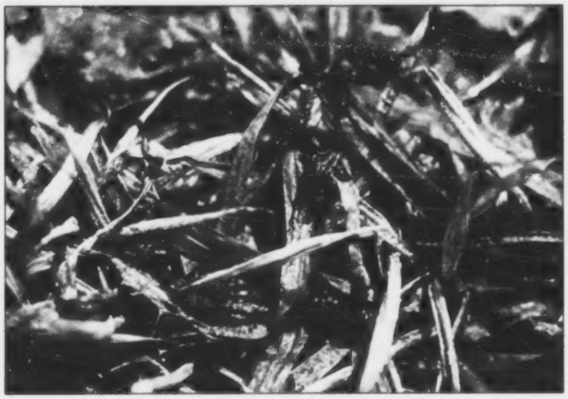


Plate 147. Snow mould appears when the snow melts after long periods of snow cover. Dead plants are slimy, brown and rotted.

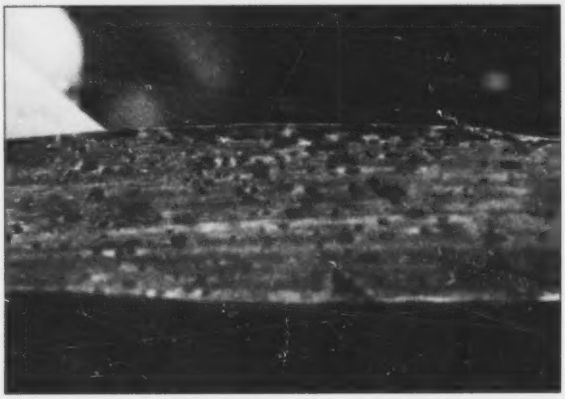


Plate 148. Leaf rust affects the leaf blades and sheath. Small, yellow-brown spots contain orange to orange-brown spores.

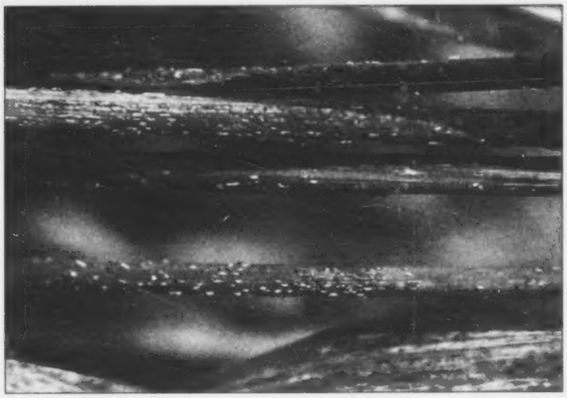


Plate 149. Stem rust can be found on the leaf sheath, stem and head.

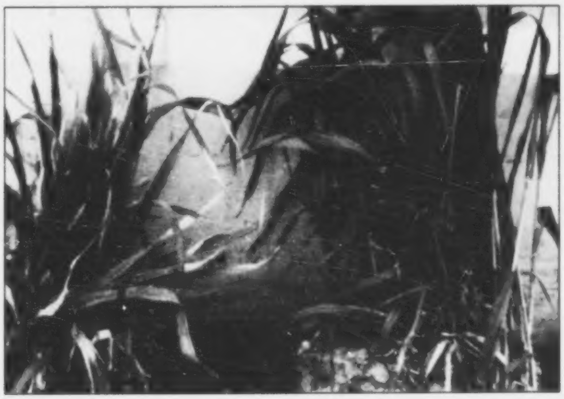


Plate 150. Barley yellow dwarf virus (BYDV) is transmitted by aphids. Symptoms are stunting and yellowing with reddening or purpling of leaf tips.

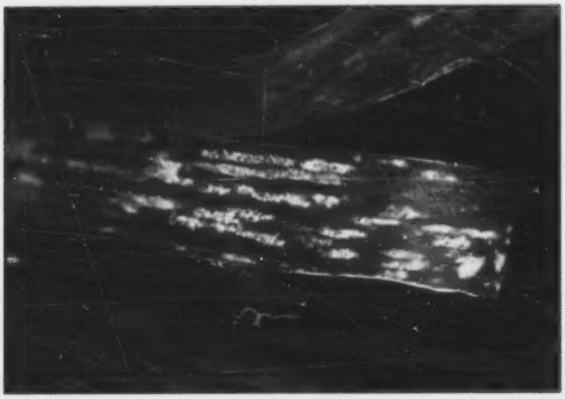


Plate 151. Powdery mildew produces a white-to-grey fungal growth on the lower leaves and moves up the plant.

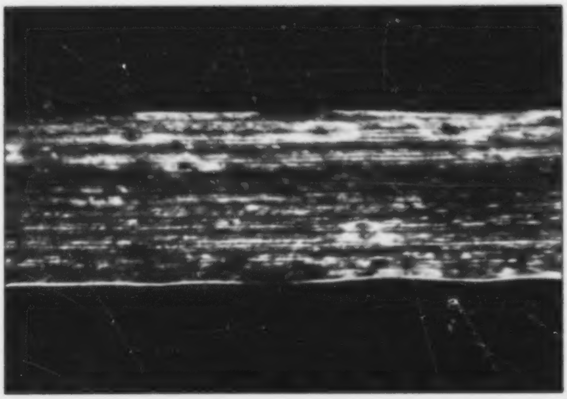


Plate 152. Septoria leaf spot appears as small, light green-to-yellow spots that elongate to form reddish-brown lesions.

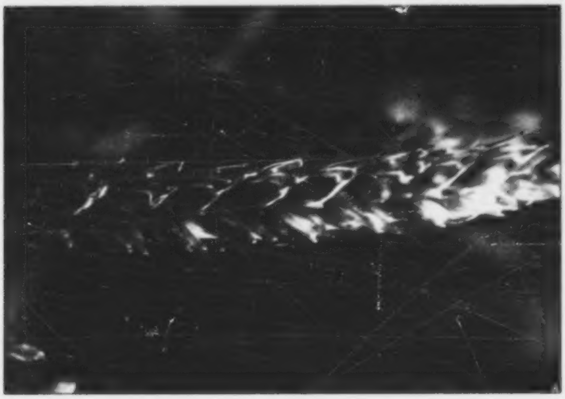


Plate 153. Septoria glume blotch appears as small, oval, grey-to-brown spots on the leaves and purplish-brown areas on the glumes.

Plate 154. Loose smut causes the kernels to be replaced by dry, black masses of spores, visible soon after the head emerges.

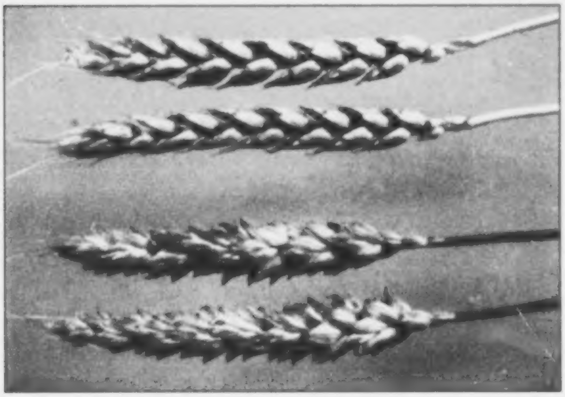


Plate 155. Fusarium head blight bleaches all or part of the head. Typically, the stem remains green.

Plate 156. Spot blotch in barley causes brown spots on the leaf and can cause seedling blight with rot appearing on the lower stem.

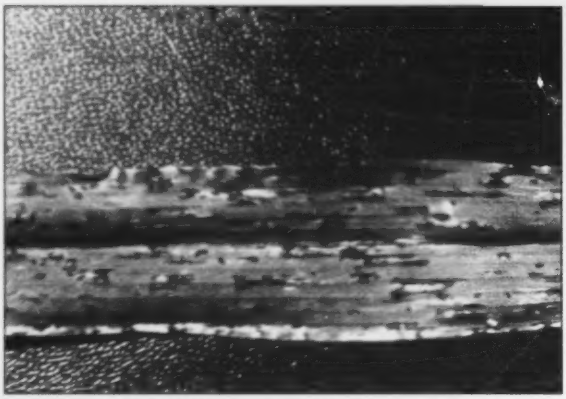


Plate 157. Net blotch starts as light green or brown spots, enlarging, with lines appearing to give a "net" appearance.

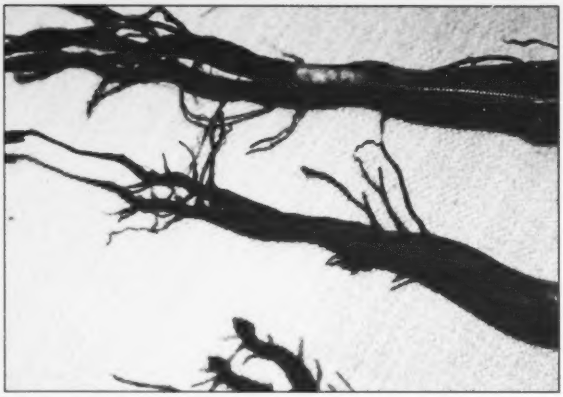


Plate 158. Root rot complex in dry edible beans is caused by several organisms. Symptoms are stunting, wilting and discoloured roots.

Plate 159. Bacterial blight begins as small, water-soaked spots on the leaflet, that join together to form large, brown, dry areas between the veins, surrounded by a yellow border.

Plate 160. Anthracnose causes round or angular lesions on the leaves, the stem and pods, which are sunken with a black ring on the edge.

Plate 161. White mould initially infects older flowers and dead leaves. Eventually it spreads to healthy pods, leaves and stems.

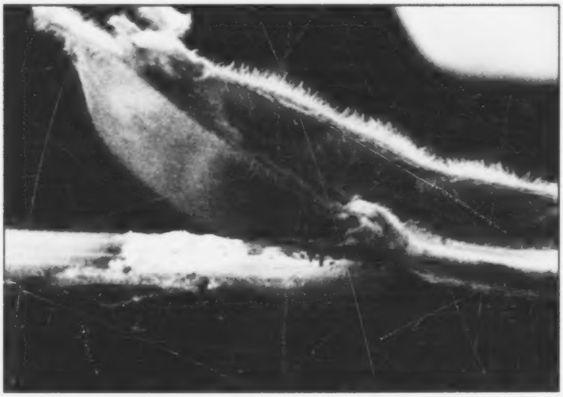


Plate 162. White mould (sclerotinia stem rot) causes white, bleached, cotton-like stem lesions.

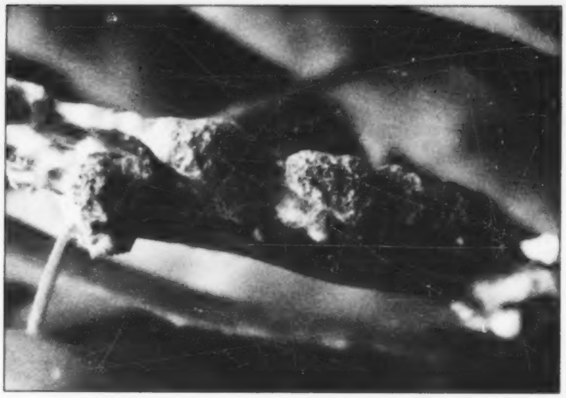


Plate 163. White mould sclerotia are hard, black bodies produced on the surface or inside the stem and pods.

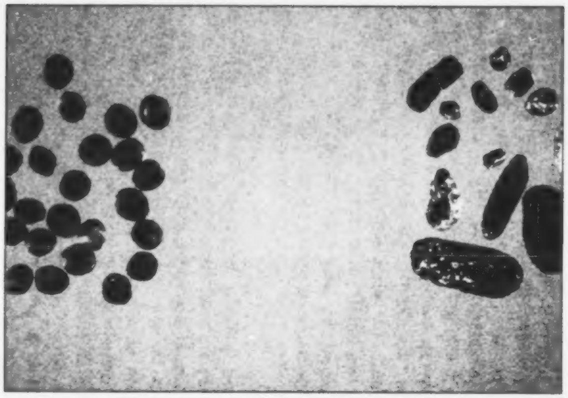


Plate 164. White mould on seed in canola. The black bodies of white mould are sometimes found in the seed at harvest.

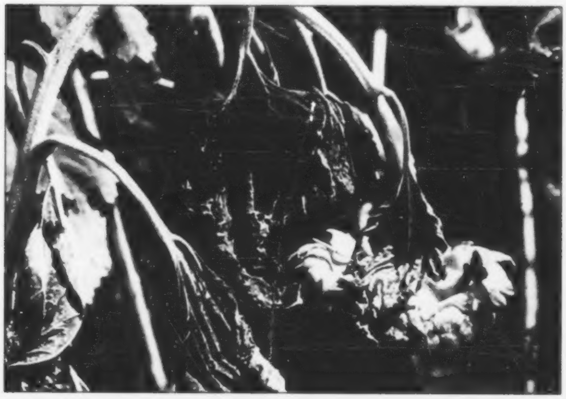


Plate 165. White mould in sunflowers causes basal stem rot, mid-stem infections and head rot.

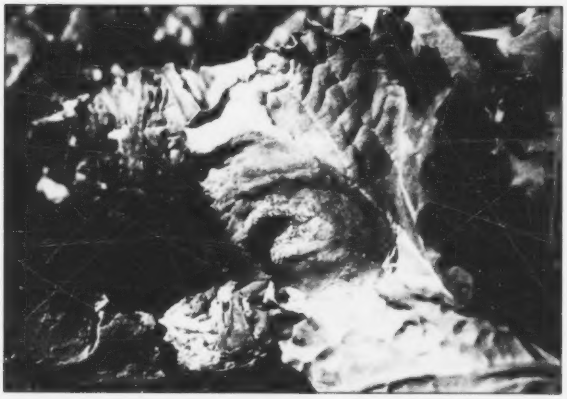


Plate 166. Blackleg in canola causes round-to-irregular, white-to-buff lesions containing many black dots (pycnidia).

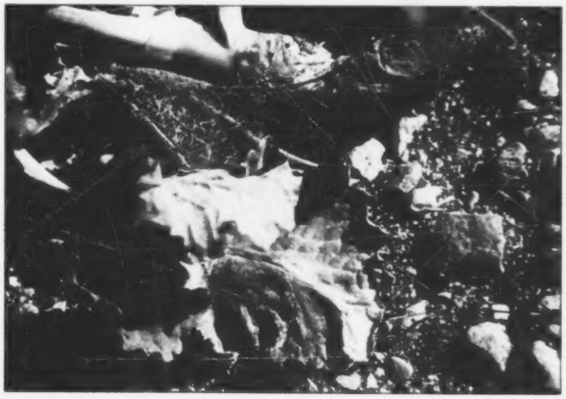


Plate 167. Blackleg spreads to the stem, producing a canker that girdles the lower stem.

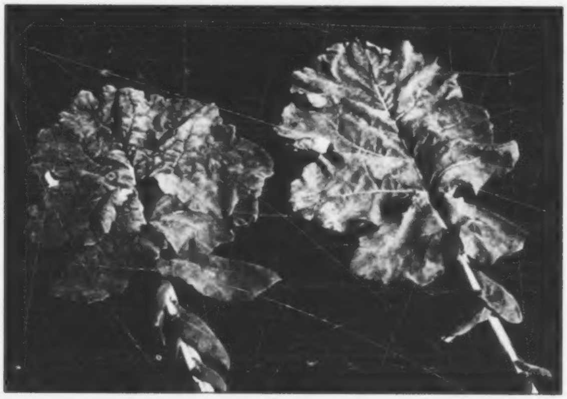
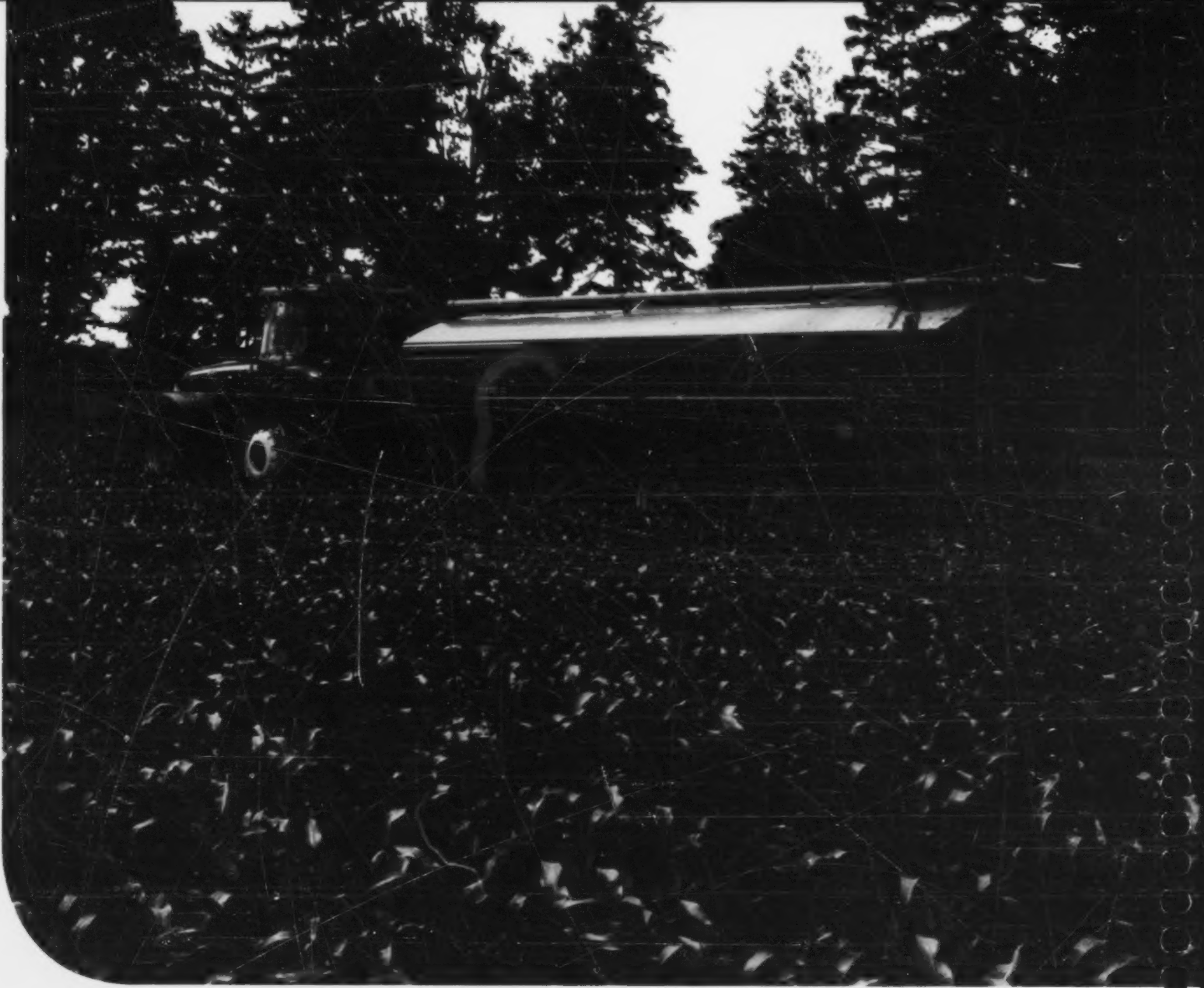
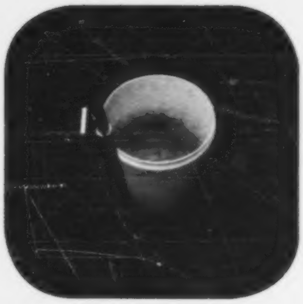


Plate 168. Turnip mosaic virus (TuMV) causes leaf mottling and wrinkling or puckering of canola leaves. It can also cause yellowing and stunting.





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